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STRATEGIC RISK MANAGEMENT IN PROJECTS: AN APPLIED MODEL TO CONTROL RISK OF PROJECTS

Behzad Abbasnejad
Chalmers University of Technology, Gothenburg, Sweden, behzada@student.chalmers.se

Mohammadreza Nejati
Abadgaran group (Construction Chemical Manufacturer), Tehran, Iran, m.nejati@abadgarangroup.com

Abstract

Risk control and management play important role to accomplish projects successfully and on time, since covering all organizational objectives and missions is considered in operational projects of organizations. Although several discussions have been considered about project management and risk management, none of them studied risk management in project management as an important factor involved in results and performance of projects and they focused on conceptual and organizational aspects of risk and generally there is no division regarding the relation between risk and projects. So by defining risks involved in project and identification, relation and extent of risks in each stage of project, an applied model has been represented to control and manage risk of projects so that we can reach desirable results of project by formulating and implementing management program of project risk with the least divergence from predetermined goals. In this direction, place of risk management has been described as one of the main function of project managers and related staff. Then features of a project, relation of risk with developmental stages of a project have been illustrated in a case matrix (in this matrix, risk rate, plan monetary value, risky price and quantity of activities in each stage of project have been shown). Finally eight stages have been presented in a form of an applied model to identify and inhibit risk of projects (comprehensive risk management cycle).

Keywords: risk management, project management, project life cycle, strategic management

1. INTRODUCTION

Risk control and management play important role to accomplish successful and on time projects, since covering all organizational objectives and missions is outlined as operational projects in organizations. Projects consist of unstructured activities (unrepeatable) and most activities are probable not certain. Further, they have a special behavior in a particular time period so they have a short life and their credit can be used in special time interval [1]. As a result, several risks may occur during projects.

In this study, it is tried to represent an applied model for risk management in project management in addition to explaining project management and position of risk in projects. After offering an operational model for risk evaluation, we are going to organize, control and manage risk based on quantitative and qualitative cases effective on performance and the result of the project. Using this method in projects provides facilities in a way that management of project quality is obtained for us due to controlled risk so that performance of the executive and project manager is flexible in each operational stage of the plan.

2. RISK MANAGEMENT OF PROJECT LIFE CYCLE

Risk management of project life cycle is a process used to control all stages involving creation, formation, documentation and control of designs risk. In other words, it helps organizations and projects to control and manage input and output costs and return of the design [1,2]. Risk management provides facilities in projects as follows:

- Successful implantation of designs and projects based on schedule and formulated executive program
- Reduction of project costs (executive, managerial costs, wages) and costs of risk effectiveness
- Reduction of stable and continuous pressures in order to improve project efficiency (saving time and using the least sources for implementing design)
- Adapting to restrictions and internal and external organizational principles
- Increase of reliability of successful implementation and accomplishment of project
- Minimizing crisis management

In order to identify matrix of risk evaluation in projects, it is necessary to explain project and its life cycle following by factors of their balance and modification, risk and risk management, risk analysis and its stages. At the end, after recognizing primary concepts, main body of research is considered and the model is presented. In this section before focusing on projects risk management, project and project management are explained. Every project has major characteristics that are shown in the following. These characteristics distinguish a project from a repeated and common activity and project manager always tries to control status quo [2].

- It has a certain goal to reach a specific result
- It has starting and ending points (reaching planned goals in a certain time)
- It includes factors of cost, source (human, technical, managerial) and time
- It has a measurable result
- Reaching quality in a certain time with a certain cost

- It is done by certain group, person or organization
- There is a certain coordination and succession in all its activities

According to above mentioned, it is concluded that each project should have certain stages (PLC) and importance of these stages is different from another depending on type of project, time and quality of activities. Regarding restrictions of cost, time and work quality (diagram no 1) moderation and balance of these stages lead to project objectives. This is one of responsibilities of project manager. Although project manager may have no experience in specialized parts of project, as an orchestra leader, he manifests his role in coordination between team members and sources in direction of reaching a joint goal [3]. According to above mentioned and importance of this issue, it is clear that in list of project manager activities, evaluation and management of risk are as important as planning time, source and determining critical points, and they should be identified, taken into account and studied. In following, list of activities has been offered: defining and determining project product, determining and recognizing accurately responsibilities, time planning, time to do works, determining and using tools required for control and evaluation, budgeting and cost, crisis management, change management, risk management, evaluating and measuring quality, quantity, time, cost and end product of project, using IT if necessary (virtual team environment) to lead project.

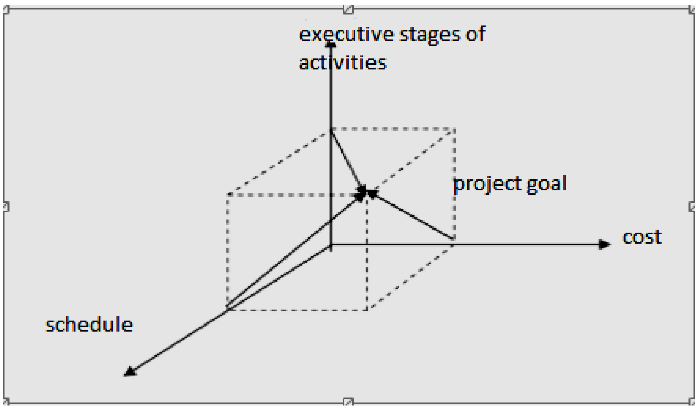

Figure 1: Project's goals and constraints

After understanding place and importance of risk management in projects, risk analysis should be considered in project management meaning risks are identified and evaluated and we are going to find how to reduce or eliminate them so that we can end projects successfully by knowing available risks and predicting strategies to control them. Risk in projects means that sources and benefits expose to losses. In order to identify all issues accompanied with possible risk, project manager should know risks explicitly because risks are inevitable parts of every project and they should be identified, controlled and managed. In order to identify a number of risks, some efforts should be taken and in all stages of the plan, it should be noted that risks can be hidden from sights until they show themselves in form of loss. In order to manage risk of project, project manager has to know types of risk and different stages of a project so that he can control and inhibit it as a potential risk and do not allow it to reach practical and effective stages. However, strategies necessary for risk control and techniques of crisis management should be determined in practical and effective stages in order to cover deficiency and failure [6,8]. It is noticeable that when we move towards end of project and final accomplishment, the number and effect of risks are limited. In diagram 2, it has been tried to show the relation between risk and each stage in addition to illustrating different stages of a plan.

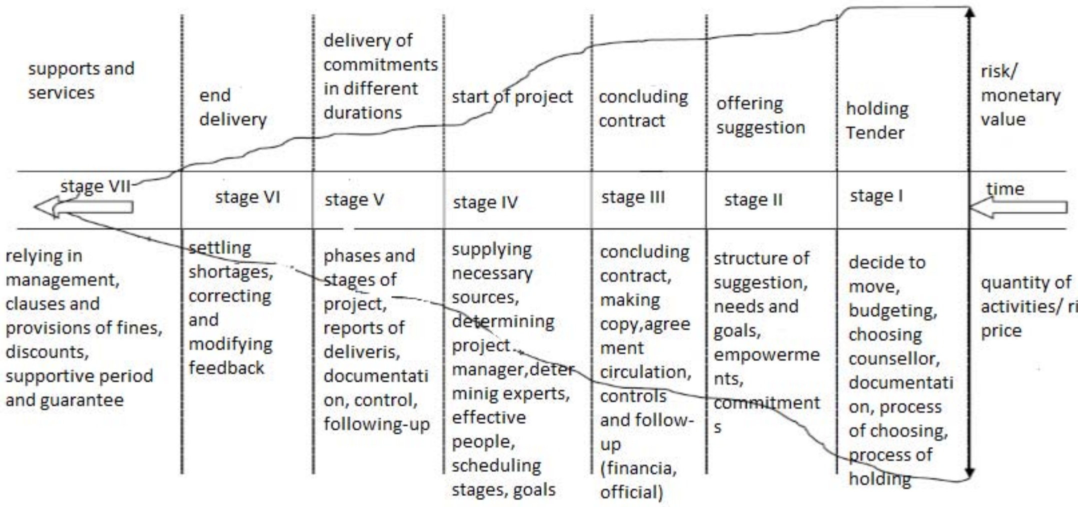

Figure 2: The relation between risk and project stages

Keep in mind that today by appearance of Information technology (IT), above stages are defined and planned in an integrated structure and in virtual collaboration environment and all above stages are controlled by tender management (stage 1), contract management (stages 2 and 3), project management (stages 4 to 6) and customer relationship and service management (stage 7) [5]. As seen in above diagram, risk management can start from primary stage of the project or in every point of project cycle and while approaching final stages, risk program also requires certain features and it changes so a risk program should be flexible to match events with our expectation in different stages in order to correct risk expectations more accurately. Therefore by planning a program for risk management in project management, complete documents will be formulated for process of identified risks and their control system based on necessary source and scheduling in case of crisis management so that safety of project result will be guaranteed in accordance with determined goals.

3. PROGRAM OF RISK MANAGEMENT

In this section it is attempted to help interested people formulate a risk management program by explaining concepts of risk management with aim of their identification and classification. As mentioned above, a project risk management program will be a complete document of process of identified risk and includes control and management systems based on scheduling of risk occurrence and sources necessary for its occurrence. This program will provide project goal safely [6,7]. In a risk program, risks are classified into three types: active/inactive, internal/external, and hidden/ none hidden. Regarding type of effects, they are continuous (long term) or temporary (short term).

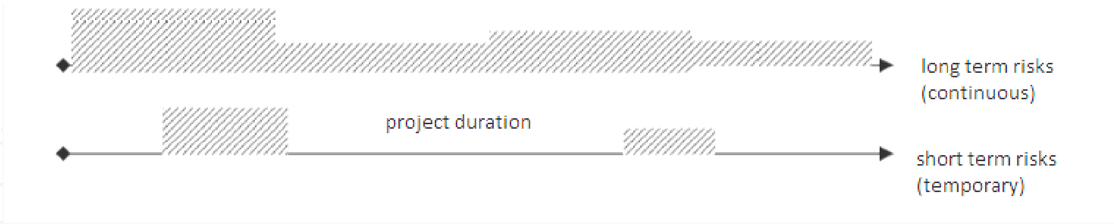

Figure 3: Continuous and Temporary risks

Active risks are those that exist ipso facto and they are inevitable but inactive risks are potential and occur under certain condition. Internal risks are those that originate from intra-organizational sources and are effective on output and work result and their input and output are controllable by organization. External risks originate from external sources of organization and are effective on organization and project goals and they are out of control of organization and it can only adapt to it but results and effects of these risks are controllable inside organizations. Hidden risks may not show themselves until they are detected and they are hidden from organization and after detection organization faces unexpected challenge but none hidden risks are identified obviously and their effect is determined (organization means project and sources related to it) [6]. Risks show themselves in different forms: single and continual

Single risks are mere and alone and are not originated from any other risks and they are not origin of other risks but continual risks cause another risk and continues hierarchically [4]. They are shown in following figure.

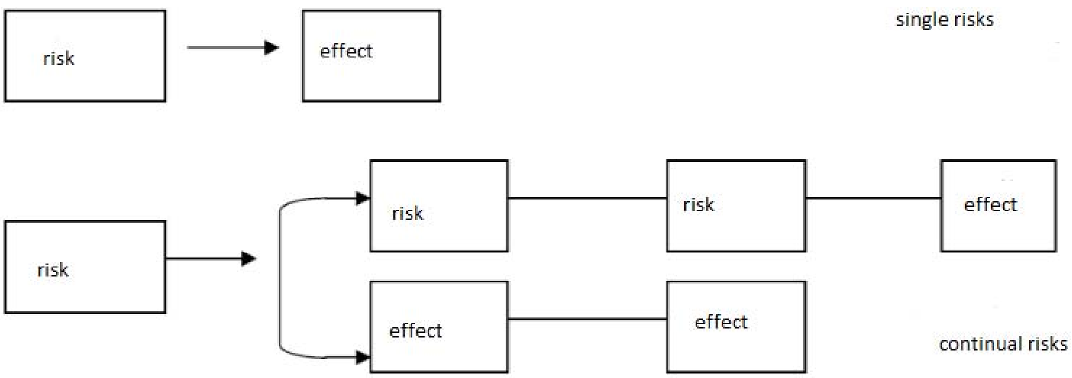

Figure 4: Single and Continual risks

4. RISK MANAGEMENT CYCLE

An applied model is outlined here to identify and control risks in projects. Since this model is process based and always is being improved and devised, it is called general risk management cycle (Fig 1). It should be noted that a successful model is used not only in project as a general system but also in components and stages of project. It acts dependent or independent in each of them [4,5]. In following chart, stages of risk management from identification to creating stability and solving effect of risk are shown.

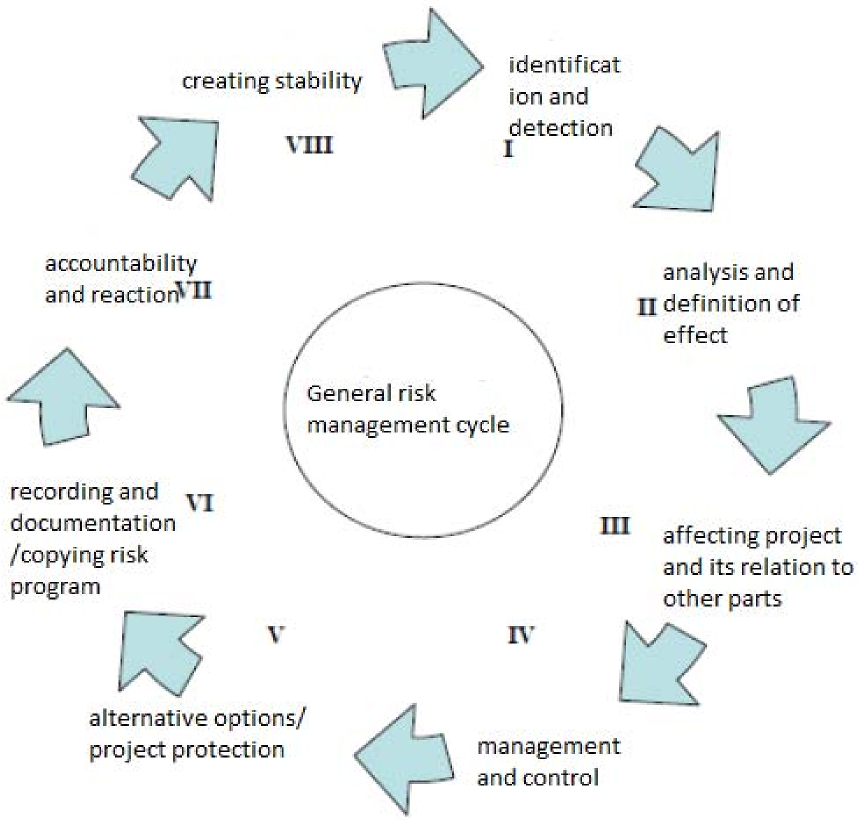

Figure 5: risk management cycle

At This cycle has no starting and ending and returns to the first stage until end of project in a process-systemic form. It repeats until end of project to become up-to-dated in direction of identifying internal and external risks. It is noteworthy that internal risks originated from internal source and condition are changeable and controllable (e.g. lack of human force in a project due to experts who left their work) bur external risks affected by external factors out of scope of project are not changeable and controllable and we should adapt ourselves to them (e.g. change of policy and governmental regulations) [7]. We should be ready to respond rapidly, certainly and easily to effects of risk with complete flexibility. Here, speed means quick response and reaction to effects of risk in order to modify and stabilize course of project. Certainly means being sure of effectiveness of performance, predicted response and having alternative solution for them. Easily means that the risk is responded with the least change in project, the least cost, simplicity in implementation and practical response. In order to know each stage of risk identification and control cycle in projects, each stage are summarized briefly:

Stage 1: identification and detection

Project manager or executive should predict all risks occurring probably in project stages (chart of relation of risk and developmental project stages): active or inactive, internal or external, hidden or none hidden [2].

Stage 2: risk analysis and effect definition

All risks identified in first stage are analyzed and defined completely. Type, rate and form of effect of each risk are examined in partial format from a general system and their effect is determined in project. Risks are classified in to single and continual ones (short and long terms) [5].

Stage 3: affecting project/ its relation to other parts

Risks analyzed in the second stage are analyzed in relation to other stages and in interaction with other risks and their effects are identified and defined. Regarding risks defined in this stage, standard deviation of project result is identified and corrected. This stage has a classification as same as above stage [5].

Stage 4: risk control and management

All managerial roles (planning, organization, leadership and control) are played by project executives in direction of risk management and definitions are offered in form of suggested solutions and crisis program if necessary. These solutions should have flexibility, speed, confidence and easiness.

Stage 5: alternative options and project protection

For each solution suggested in stage 4 that is used while occurring risk, alternative options are recommended. In fact other responses are suggested that are used in critical conditions because we may not be able to use the first solution regarding limitations and time requirements while occurring a risk. At this time, we use supports and alternatives. For example, in course of project stages, project manager suffers acute disease. So here option of risk control plays role meaning project manager assistant but if project assistant is not used accidentally, will project be ended? Yes or no. alternative option solves this small problem and one of project members whose ability has been analyzed, plays this role and the project will end [8,9].

Stage 6: recording and documentation/ copying risk program

In order to use optimally all above mentioned stages, they should be recorded and documented. It is documentation that is source of risk program. In this program, risks are scheduled based on their date of occurrence and prioritized based on sequence and significance of project stages. For each risk, its effectiveness on the project and relation to other parts, its control and management have been described. An important point is that the program should up-to date regarding progress of project stages [8].

Stage 7: accountability and reaction

Running predicted solution or a common solution and support is called accountability and reaction to risk. All sources should be ready in determined intervals based on risk schedule so that they can be used upon feeling risk [6].

Stage 8: creating stability based on project goals

After stage 7, it is expected the project to be stabilized and to return to its first stage and desirable performance is provided. In some situations, risk does not occur according to timed and predicted program thereby stability of project is created without delay and change [7].

Above-mentioned stages are operational steps that protect us from destructive effects and risk in order to reach goals of our activities with high confidence and low source.

3. CONCLUSIONS

Considering nature and features of projects that describe special characteristics such as cost, time, quality and certain sources, covering objectives of these projects requires complex programs but with simple implementation in order to be used practically. Planning to control and manage project risk guarantees its success. In addition to operational power of managers in implementing projects, risk management programs play important role in this process. A risk management program with several advantages and consequences and also with comprehensive definition ranged from risk identification and definition to its control in organization, can be an important reference for organizational strategic planning, by designing above risk management program, we are able to respond stimulants, unexpected internal and external changes and issues and to promote personal and organizational efficiency and effectiveness.

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THE PROCESS OF SCAFFOLDING PLANNING FOR EXTENSIVE RENOVATIONS OF HIGH-RISE CONDOMINIUMS

Tetsukazu Akiyama
Toyo University, Saitama, Japan, akiyama@toyo.jp

Ryosuke Fujiki
Space Union, Tokyo, Japan, r_fujiki@spaceunion.co.jp

Abstract

The number of high-rise condominiums in Japan has increased dramatically since the 1990's. In the last few years, more and more of these buildings have required the first round of major repairs, including work on their exterior walls. Nevertheless, the condominium renovation sector lacks the experience and information needed to work with high-rise condominiums. It is usually the case that the designer (architect-engineer) of the overall condominium renovation is responsible for scaffolding planning as well. However, high-rise condominium renovations often involve the use of gondola scaffolding. This kind of scaffolding requires that a variety of factors be taken into account, including scaffolding placement methods and types of gondolas. The scaffolding designer must select the most appropriate kind of scaffolding from a variety of types, including gondolas. Unfortunately, generalized standards for the basis of such a selection do not exist. Thus designers are left without sufficient resources for scaffolding planning.

This study focuses on the following two elements in the process of scaffolding planning for extensive high-rise condominium renovations:

1. The process of scaffolding planning and its complications; and

2. Simulations of different scaffolding types and the corresponding placement costs.

Keywords: high-rise condominium renovations, scaffolding planning, designer’s role, placement costs.

1. INTRODUCTION

The number of high-rise condominiums[1] in Japan has increased dramatically since the 1990's. In the last few years, more and more of these buildings have required the first round of extensive renovations, including to their exterior walls. Nevertheless, the condominium renovation sector lacks the experience and information needed to work with high-rise condominiums. Thus, scaffolding planning and other renovation methods for this type of buildings are not yet mature. Renovation methods used for medium-height condominiums can be applied to the exterior wall repairs and waterproofing of high-rise buildings. The same cannot be said with regard to scaffolding planning.

It is usually the case that the designer of the condominium renovation is responsible for scaffolding planning as well. When carrying out extensive renovations of medium-height condominiums, frame type scaffolding is often used. Designers in this case can propose appropriate scaffoldings based on their past experiences without much difficulty. However, extensive renovations of high-rise condominiums often involve the use of gondola scaffolding. The planning of this kind of scaffolding requires that a variety of factors be taken into account, including scaffolding installation methods and types of gondolas. Furthermore, work on high-rise condominiums can involve not only gondola scaffolding, but also frame type scaffolding as well as special systems developed by construction firms. Therefore, the designer must select the most appropriate kinds of scaffolding from a variety of types, not just gondolas. Unfortunately, generalized standards for the basis of such a selection do not exist. Thus, designers are left without sufficient resources for scaffolding planning, making it difficult for them to plan scaffolding methods on their own.

Compared to medium-height condominiums, scaffolding planning for high-rise condominiums has a significant influence on the cost, quality and duration of the renovation work. Thus, the immaturity of scaffolding planning methods is a grave problem that cannot be ignored. The improvement of these methods is vital to the maintenance and preservation of high-rise condominiums, and therefore it must be dealt with immediately.

2. OVERVIEW OF THE STUDY

2.1. Objectives

This study aims to contribute to the improvement of scaffolding planning for high-rise condominiums. More specifically, the following issues are examined and evaluated:

(1) The process of scaffolding planning for extensive renovations of high-rise condominiums, and its complications

(2) Simulations of different scaffolding types and the corresponding installation costs for extensive renovations of high-rise condominiums

2.2. Examples

(1) Overview of the Examples

Extensive renovations of condominiums are carried out either by using the design-bid-build approach or the design-build approach. In general, clients without technical knowledge gain more transparency in terms of construction cost and quantity of work when they hire a designer/supervisor and a contractor separately. Therefore, this study analyzed examples of extensive renovations of high-rise condominiums that were executed according to the design[2] and under the supervision[3] of an architectural firm.

Because scaffolding installation methods for high-rise condominiums are improving steadily, recent renovations should be used as examples. At present, however, examples of high-rise condominium renovations are scarce, and cases with separate designer/supervisor and contractor are even more limited. Despite this scarcity, we found an architectural firm, which we will refer to as Architectural Firm S, that was in charge of the design and supervision of two high-rise condominium renovations in 2007 and 2008. This paper analyzes these very recent sets of data. Architectural Firm S also has on record another such renovation, which was carried out between 1997 and 1998. Therefore, all three sets of data were used as examples to study the process of scaffolding planning and scaffolding installation costs. These examples are listed in Table 1.

Name of the Condominium	Building Overview					Overview of the 1st Extensive Renovation			
	Year built	Number of Floors	Number of Buildings	Number of Units	Type of Building	Year		contractor	Duration of Work
N	1988	25	3	576	Lightwell	1997-98	10 years old	Firms O and T (JV)	10 months
C	1992	31	1	290	Central hall	2007-08	16 years old	Firm A	10 months
Y	1993	25	1	367	Lightwell	2008	16 years old	Firm K	6 months

Table 1: Overview of the Examples

(2) Characteristics of the Examples

One of the characteristics of the process of scaffolding planning for high-rise condominiums at Architectural Firm S is that they actively take into account suggestions provided by their contractors. Though the designer must select the most appropriate scaffolding methods from a variety of types, it is rather difficult for the designer to make that decision alone. Architectural Firm S supplements their scaffolding planning capability by reflecting contractors' opinions in the process. This paper examines this method of scaffolding planning, and explores such methods that do not rely solely on the designer.

3. THE PROCESS OF SCAFFOLDING PLANNING FOR EXTENSIVE RENOVATIONS OF HIGH-RISE CONDOMINIUMS, AND ITS COMPLICATIONS

3.1. The Process of Scaffolding Planning for High-rise Condominiums

The process of scaffolding planning for high-rise condominiums is examined using Architectural Firm S's data. Figure 1 graphically shows this planning process, which was used in all three high-rise condominium renovations. This scaffolding planning process is as described below:

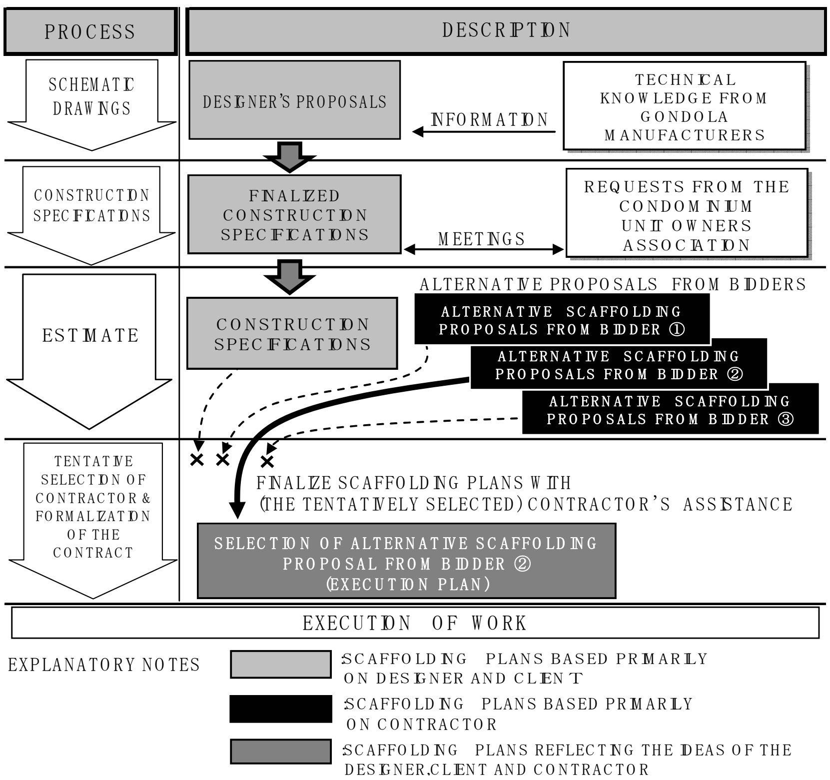

Figure 1: The Process of Scaffolding Planning for High-rise Condominiums

(1) Schematic Drawings and Construction Specifications

When carrying out scaffolding planning for medium-height condominiums, designers can rely on their past experiences and mainly use stationary scaffolding. However, scaffolding planning for high-rise condominiums does not allow them to depend on their experience.

In scaffolding planning for high-rise condominiums, how to incorporate gondola scaffolding into the plan is an important issue. It must be noted that there are a wide variety of installation methods for gondola scaffolding. There are cases where both gondola and frame type scaffolding are used, and yet other occasions in which frame type scaffolding is installed all the way to the top of the building. Given that high-rise condominium renovations are scarce and therefore related technical experience is insufficient, designers have limited resources to help them in selecting appropriate types of scaffolding from such a wide variety without other input.

In an effort to overcome this deficiency, Architectural Firm S sought gondola manufacturers' technical assistance in the preparation of their scaffolding plans. Then they met with their clients, i.e. condominium unit owners associations (CUOAs). Technical advancements in gondola scaffolding have been remarkable in recent years, and many new kinds of gondolas have appeared. Many of these contributions have been made by large gondola manufacturers. Thus, it is worthwhile for designers to obtain the most updated information from gondola manufacturers.

After considering gondola manufacturers' recommendations, the designer presents scaffolding plans that center around the use of gondola scaffolding to the CUOA. These plans also include multiple protective measures associated with the use of gondola scaffolding. The designer and the CUOA discuss issues such as ways to ensure residents' comfort during the renovation and the estimated costs of the scaffolding installation. After this phase, the different interventions included in the renovation are identified, and construction specifications for the appropriate scaffoldings are drawn. In the case of high-rise condominiums, it is common for their cladding to include tiles or steel sheets. If such materials are not in an extremely poor condition, it may be sufficient to simply replace the sealing agents in the joints of the surface materials. In that case, it is possible to use individual gondolas without any protective measures, rather than a gondola system with splatter prevention incorporated (e.g. covering the entire building with protective mesh). In other words, scaffolding installation methods vary greatly depending on the nature of the work that is to be realized.

(2) Requesting Estimates

The CUOA then sends the renovation's construction specifications to multiple construction firms, requesting estimates for the project. In addition to requesting estimates, the CUOAs in the example cases also asked these firms (the bidders) to cost analyze other types of scaffolding that they believed would be appropriate.

There are several reasons why alternative scaffolding proposals are requested:

Gondola scaffolding permits only a limited number of people to work at a time. Therefore, during the process of scaffolding planning, it is necessary to take into account the construction work schedule, which is usually proposed by the contractor. This work schedule includes the number of workers, job duration, and the division of the project into sections. Scaffolding specifications in the estimate stage arise mainly from the designer, gondola manufacturers and the CUOA. In other words, their compatibility with a construction work schedule is not taken into consideration. The idea of requesting alternative scaffolding proposals came about as a way to obtain the contractors' suggestions, which take work schedules into account.

As described earlier, scaffolding specifications for high-rise condominiums in the schematic drawing and construction specification phase are based mainly on the use of gondola scaffolding. In reality, however, there are situations when only frame type scaffolding is used even for high-rise condominiums. There also exist occasions when both frame and gondola types are used together. Furthermore, some construction firms use scaffolding systems that they have devised. Thus, alternative scaffolding proposals from construction firms are used in order to introduce other scaffolding methods apart from gondolas into the process of scaffolding planning.

(3) Tentative Selection of the Contractor and Construction Contract

The designer and the CUOA study the cost estimates and the alternative scaffolding proposals submitted by the bidders. They then interview each bidder to learn more about their scaffolding proposal. After this step, the owners association considers the price, different approaches to scaffolding, and impressions given from the interviews to tentatively select a construction firm to execute the work.

The cost of scaffolding installation for high-rise condominiums is approximately 20% of the total price of the renovation. This amount is therefore a significant part of the overall cost. Nevertheless, the type of scaffolding and its installation fees are only one element in the selection of a contractor. Other determining factors include the overall cost of the project (including scaffolding) and the reliability of the on-site representatives of the contractors.

After a contractor is tentatively selected, the designer and the CUOA meet with that contractor to evaluate various scaffolding methods, including the ones proposed by the contractor and the designer, as well as alternative proposals given by unsuccessful bidders. Then they select the appropriate scaffolding for the project. Finally, a general meeting of the CUOA is held, after which a construction contract is signed.

3.2. Complications with the Process of Scaffolding Planning for High-rise Condominiums

Based on the various factors discussed in the previous subsection, we identify complications that may arise during the process of scaffolding planning.

(1) Complications During the Schematic Drawing and Construction Specification Phase

In the three renovations, none of their construction specifications incorporated special scaffolding systems developed by gondola manufacturers.

The designer of these projects prepared scaffolding plans with the technical assistance of gondola manufacturers. In such occasions, designers must be cautious about using gondola manufacturers' special systems including those that are patented. Choosing some special systems implies the need to contract one particular gondola manufacturer for that renovation project. This decision could dampen price competition, which in turn may cause the scaffolding installation cost to inflate. It is therefore desirable to prioritize more commonly used scaffolding systems as much as possible during the phase of schematic drawing and construction specification. Thus, the scaffolding specifications in the three examples included only commonly used scaffolding systems.

Despite the fact that this type of scaffolding planning involves the collaboration of gondola manufacturers from the beginning, the resulting scaffolding specifications do not include the manufacturers' latest gondola systems. Moreover, another problem with this process is that frame type scaffolding is not considered during the preparation of construction specifications.

(2) Complications During the Estimate Phase

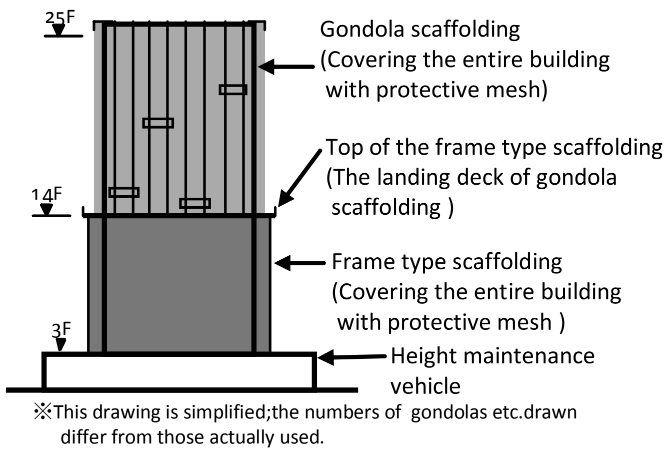

Figure 2: Schematic Drawing of the Scaffolding for Condominium Y

In the three examples of high-rise condominium renovations, the designer and the CUOAs resolved the problems identified in the preceding subsection by inviting bidders to propose alternative scaffolding systems along with the submission of their estimates. Thus, the designer and the associations collected a wide variety of scaffolding options. However, none of the scaffolding proposals from the bidders included the latest special systems. Instead, most of them advocated frame type scaffolding.

When the initial construction specifications for Condominium Y were first prepared, gondolas were used from the third floor. However, the contractor suggested the use of frame type scaffolding up to the middle of the building and only the use of gondola scaffolding above that.

The renovations of Condominiums N and C also had bidders who suggested the use of frame type scaffolding up to the middle of the building during the estimate phase, but this type of scaffolding was not used in the end. In Condominium N, this idea was rejected because it was believed to be difficult to obtain the consent of the residents if different scaffolding systems were used for the top and bottom halves of the buildings. This is due to the fact that different scaffolding systems would affect residents differently depending upon which floor they lived on.

Frame type scaffolding was also rejected in the Condominium C project. This high-rise building has a protruding roof in its lower portion. This roof made it difficult for frame type scaffolding to be set up right below the gondolas. Also, its exterior walls were covered with panels of glass fiber reinforced concrete (GRC) and a careful investigation revealed that the anchors used for the installation of frame type scaffolding could not be attached to such surfaces.

As mentioned above, bidders tend to find that proposing the use of frame type scaffolding is much simpler than the use of special gondola scaffolding systems. Bidders calculate the cost of the work based on the ease of the job and other factors. Because the use of gondola scaffolding affects various factors, such as the number of workers, bidders tend to avoid incorporating such unfamiliar new scaffolding systems in their proposals. Such special systems also tend to be more costly than commonly used systems. The bidder's principal aim is to reduce their estimate of the construction costs to increase the likelihood of their being contracted. Thus, even when a special system is believed to improve the quality of the work, bidders are not likely to propose its use for the fear of inflating their estimate.

On the other hand, abundant technical information regarding frame type scaffolding allows bidders to calculate the work involved in the job more easily. Frame type scaffolding also leads to higher work efficiency than does the use of gondolas. These advantages of frame type scaffolding are likely to have led many of the bidders to recommend it in their proposals.

(3) Complications During the Finalization of the Scaffolding Specifications (After a Construction Firm is Tentatively Selected)

In both high-rise and medium-height condominium renovations, scaffolding plans are finalized after their initial specifications are prepared, estimates are evaluated and a contractor is tentatively selected. However, scaffolding specifications in both of these cases are prepared with different expectations during the specifications phase.

In the case of medium-height condominiums, scaffolding specifications are formulated based upon the assumption that they will be applied without modifications. For high-rise condominiums, however, scaffolding specifications are prepared as reference specifications and are used to evaluate bidders' scaffolding proposals. In other words, for a high-rise condominium renovation, the designer, the CUOA and the contractor must agree upon the integration of the different proposals before scaffolding specifications are finalized.

(4) Summary of the Complications During the Scaffolding Planning Process of the Examples

The designer in the three example renovations could not incorporate the latest special scaffolding systems, despite the fact that they had technical assistance from gondola manufacturers. The bidders, on the other hand, did not include such new systems into their proposals, but rather preferred scaffoldings based on their experience and concerns about cost. Thus, we believe that the latest special gondola scaffoldings are not likely to be adopted in this type of scaffolding planning process.

Our analysis of the scaffolding planning process suggests that it would be advisable to incorporate construction firms' suggestions earlier. If this were the case, work schedules would be taken into consideration when formulating scaffolding plans. However, in order to ensure the fairness of the bidding process, designers should not ask construction firms for alternative suggestions prior to the estimate phase. Exactly how construction firms' alternative proposals can be more effectively incorporated into the process of scaffolding planning remains to be resolved.

4. SIMULATIONS OF SCAFFOLDING INSTALLATION COSTS

The previous section dealt with the process of scaffolding planning used in the example renovations. In all of the three renovations, the bidders proposed the use of frame type scaffolding up to the middle of the building during the contractor selection phase. As explained earlier, frame type scaffolding allows bidders to more easily predict how the work will progress than in the case of gondolas. Furthermore, the former method does not limit the number of workers as much as the latter. In other words, frame type scaffolding is an effective method even for high-rise condominiums, as it provides contractors with many advantages in the execution of the work.

The use of frame type scaffolding for all floors of a high-rise building would require that the strength of the scaffolding components be evaluated and then correspondingly reinforced. Given the cost of such reinforcement, the length of time that would be necessary to set up scaffolding of that height and the cost of elevating the scaffolding components, it is likely that installing frame type scaffolding for the entire building would lead to an increase in cost.

This subsection presents simulated scaffolding installation costs for different scenarios in the case of Condominium Y. These simulations were made possible by the collaboration of Firm K, the contractor that renovated this condominium. Three different scenarios were used in the simulations: only using gondola scaffolding, only using frame type scaffolding, and the use of both together. The nature of the relationship between the types and corresponding costs of the scaffolding was examined based upon these simulations.

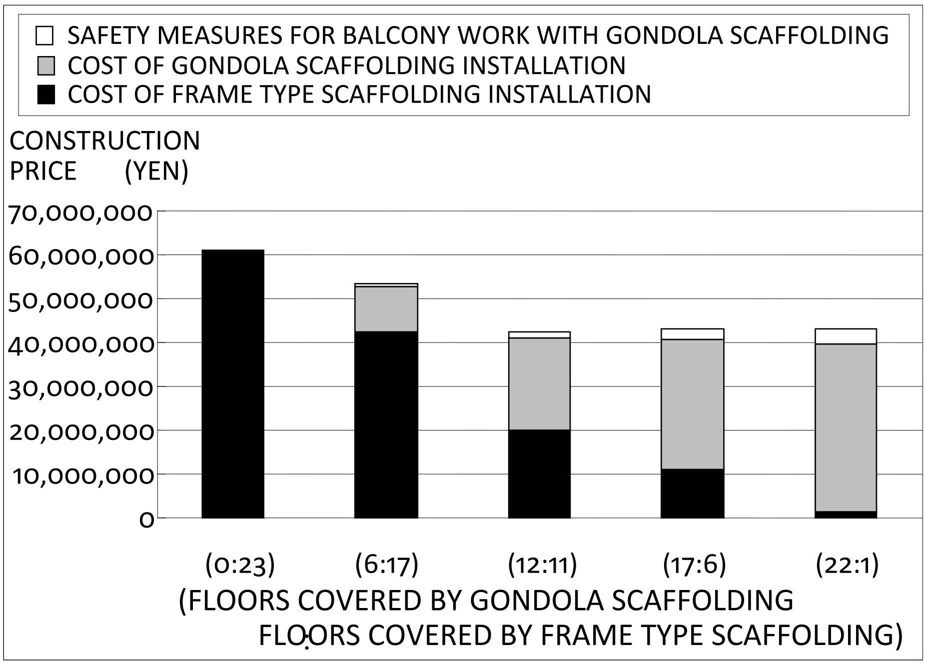

Figure 3: Simulations of Frame-type and Gondola Scaffolding and Their Corresponding Installation Costs

According to Firm K's simulations of the different scaffolding installation costs, as shown in Figure 3, the most expensive option (61,088,000 Yen) was that of installing frame type scaffolding over the entire building. The least expensive option (42,485,600 Yen) was to install frame type scaffolding only up to the 13th floor.

(1) Installation Costs of Frame Type Scaffolding When Installed to Reach the Upper Floors

Installing frame type scaffolding to reach the upper floors adds the costs of reinforcement and elevation to the overall installation cost. The unit price of the installation in this case is therefore expected to be higher than that when frame type scaffolding is installed only over the lower floors. The unit price per square meter is calculated by dividing the total installation cost of the scaffolding by the area covered by that scaffolding.

We calculated the unit prices of scaffolding installation for all of Firm K's simulations. The results of these calculations show that installing frame type scaffolding for the entire building would cost approximately 4,600 Yen per square meter, whereas the unit price would be approximately 4,300 Yen per square meter when erected up to the 19th floor, approximately 3,100 Yen per square meter when used up to either the 13th or the 8th floors, and 2,300 Yen per square meter when set up only until the third floor level.

In contrast, the unit price of employing gondola scaffolding is approximately 3,000 Yen per square meter, and this cost is not dependent upon the number of floors to be covered.

Thus, placing frame type scaffolding all way to the top or up to the nineteenth floor would cost either approximately 4,600 or 4,300 Yen per square meter, which is much higher than the unit price of 3,000 Yen for gondola scaffolding. In this case, therefore, frame type scaffolding is inferior to gondola scaffolding in terms of cost.

(2) Installation Costs of Frame Type Scaffolding When Used up to the Middle or Lower Floors

As discussed above, the unit price of frame type scaffolding installation becomes elevated when this type of scaffolding is used to reach the upper floors of high-rise buildings, making this type of scaffolding inferior to gondola scaffolding in terms of cost under such conditions.

On the other hand, when frame type scaffolding is used up to the 13th floor, the unit price goes down to approximately 3,100 Yen per square meter. This cost does not differ significantly from that of placing gondola scaffolding. Therefore, the simulated scaffolding installation costs for when frame type scaffolding was used either to the thirteenth floor or the eighth floor, or only up to the third floor level did not differ greatly from one another.

However, with more extensive use of gondola scaffolding the associated costs become higher. Such costs include security measures employed for the tasks executed on balconies. Thus, among the three simulated cases with the lowest unit prices, that of installing frame type scaffolding up to the thirteenth floor is deemed the most economical as this scenario requires the least number of floors to be covered by gondola scaffolding. In fact, this option was used in the actual renovation work of Condominium Y.

(3) Scaffolding Selection Methods From the Perspective of Installation Costs

In summary, the most economical method is to install frame type scaffolding to the height where its unit price surpasses that of gondola scaffolding. It must be noted, however, that this conclusion is based only upon our cost-based analysis. In other words, the merits and disadvantages of utilizing this method in reality have not been considered. Generally, gondolas move only vertically, thus limiting the horizontal movements of workers. In the case of Condominium Y, the fact that its balconies were divided only by panels was fortunate. Removing those panels allowed the workers to move horizontally all the way around the building at each floor level. When balconies are physically separated from one another, the same arrangement cannot be made. In such cases, it may be better to erect frame type scaffolding as high up as possible, but while taking into consideration the cost and schedule of the work involved.

5. CONCLUSIONS

There is an increase in the use of the design-bid-build approach in extensive renovations of high-rise, as well as medium-height, condominiums. However, as discussed in Section 3, contractors' suggestions should be taken into consideration during the process of scaffolding planning for high-rise condominiums. Establishing ways to actively incorporate their alternative proposals during renovation planning is essential. In our examples, alternative scaffolding proposals were requested from bidders during the estimate phase. Another possibility would be to request bidders' scaffolding suggestions during the specification preparation phase. In Section 3, we pointed out that the bidders tended to avoid the latest special scaffolding systems. If they are asked to propose alternative scaffolding systems independent of their costs during the specification preparation phase, they may be more likely to include the latest systems in their suggestions.

Currently, gondola scaffolding is the type considered most advantageous for extensive high-rise condominium renovations. However, we examined the possibilities arising from the use of frame type scaffolding in Section 4. Based on our analysis, we conclude that scaffolding systems that match each high-rise condominium's characteristics must be selected for its renovation, rather than simply assuming that gondola scaffolding is best suited for any high-rise building.

Gondola manufacturers and a variety of other organizations are working on developing new scaffolding systems for high-rise condominiums. But, if these systems are not used in reality, their development is meaningless. Efforts must be made to encourage the use of such systems during the process of renovation planning. Furthermore, as we have done in this study, it is important to reassess the overall planning process of extensive high-rise condominium renovations.

ENDNOTES

[1] Under the Japanese Building Standards Act, buildings over 60 meters high are defined as "high-rise buildings." While there does not exist any legal definition of "high-rise condominiums," this study defines them as those that have 20 or more floors.

[2] The designer of an extensive condominium renovation specifies the scope of each type of work, repair methods, scaffolding types and installation methods, construction materials used, the quantity of the paint applied, and so on.

[3] When the extensive renovation of a condominium is carried out by the design-bid-build approach, the supervisor's principal responsibility is to ensure that the work is carried out in accordance with the construction specifications.

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A STUDY ON THE OPERTATIONAL READINESS OF MEGA CONSTRUCTION PROJECT

Jumah Rashed Al Mazrooie

The British University in Dubai, Dubai, UAE, 120020@student.buid.ac.ae

Arun Bajracharya

The British University in Dubai, Dubai, UAE, arun.bajracharya@buid.ac.ae

Abstract

It is important that the transition between construction and operational phases be managed properly. It is crucial especially for prestigious mega projects in which large mass of public is served from day one of the real operational phase. Faulty and dysfunctional elements in the completed project systems would not only create interruptions and delays but it could also tarnish the public image of the project. The costs of such consequences could be high and it would be an additional unforeseen cost burden for the project.

Generally mega projects are planned with fast track approach with high pressure to start-up the operations at earliest time. There would be overlaps in the schedules of the last stage construction activities and the activities related to operational preparations. The interference between the two sets of activities might create interruptions, errors, and consequent reworks at both sides. The errors that creep into the operational preparations might be discovered only after the real operational phase, and it might create surprise rework and interruptions. This research attempts to develop a model that can portray the interaction between the workflows at the last stage of construction and the operational preparations. System dynamics approach has been utilized to develop the model. Observations in one of the mega projects in Dubai that recently came in operation have been used to structure the model. Experimental study with the model revealed that the key to avoid the majority of the interface problems is to integrate the operational preparation activities into the construction activities. The client should appreciate the operational preparations as part of the whole project and thus the operational readiness program should be integrated in the project plan to eliminate any reluctance or uncertainties by the main contractor.

Keywords: Interface management, construction and operational phases, operational readiness, mega project, dynamic modeling.

1. INTRODUCTION

In the past decade demand for large scale infrastructure projects such as airports, railways, seaports has increased rapidly to accommodate the increasing needs and requirements of public services. Many large scale infrastructure projects or mega projects have been constructed and operated in a fast track manner that enabled the clients and governments to have a quick beneficial use of the service and facilities. Some of the mega projects prolong the operations ramp-up in a long time span. However they still fail or struggle even though they have a longer ramp-up period. According to Richard (1994) the government in Denver had to bear a total cost of \$33 million/month because of delay in airport opening due to major problems in baggage handling system.

According to a general understanding in project management, a project life cycle starts from the conceptualization of the project idea and it gets terminated when it has been handed over to the client. However, the operational phase of the project is often overlooked to be integrated with the execution phase. Wit (1988, p.166) has clearly stated that “Project management books usually omit the operational phase because they tend to be written from a consultant’s or contractor’s perspective”. Dvir et al. (2003) argued that problems may start to surface in the initial phase of operations that may result in drifting or low level of performance of the services. This results in the reputational and financial impacts on clients as shown in Figure 1.

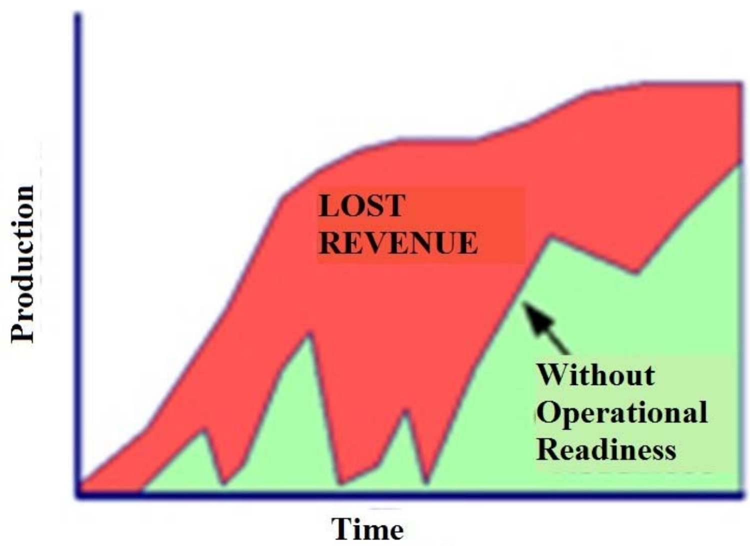

Figure 1 : Losses Due to Operational Problems (Source: Honeywell (2012))

A review by Dvir et al. (2003) also stated end-user satisfaction is one of the elements of the project success. Such satisfaction will only be achieved if the operational phase of the project has been carefully started after the execution phase. The followings are some of the indicators of the project failure during operational phase:

- Defects start to arise in systems installed in the project.
- Defects start to arise in facilities of the project.
- Human errors due to lack of training and familiarization on the operational systems.
- Absence of operational model and procedures.

Project clients need to introduce an operational readiness program to identify and minimize the risks of operational failure after handover of mega projects (Alessendri et al., 2004), and as such the mitigation of the identified risks should be in place. In order to enable the operational team to get trained and familiarized, the operational readiness programs need to run in parallel with the execution and closing out phases (see Figure 2). Another reason for running the operational readiness program is to allow the operational team to establish and confirm the intended model of operations for the project before start up.

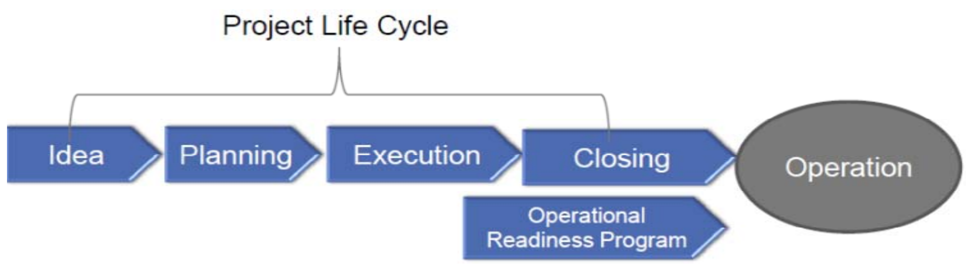

Figure 2 : Project Life Cycle

Operational readiness program is a set of operational activities and trials that need to be performed on mega projects such as airports before going live. Usually these activities and trials are not in the main contractor's scope of work and it requires coordination between relevant stakeholders. Below are some examples of the activities that will be carried out in an operational readiness program for an airport:

Tasks	**Type**	**End-Users**
Fire certification and training	Training & familiarization	Airport fire department
Lost bag process	Trial	Airport operational team
Fire evacuation drills	Trial	All airport users
Aircraft maneuverability	Trial	Airside operational team
Security system training	Training	Airport police department
Baggage handling process	Training	Airport baggage team
Airport's Staff Access	Training	All Airport staff
Passenger and crew handling	Trial	Airline operational team
Cargo and Mail handling	Trial	Airline operational team
Facilities and systems	Training	Airport maintenance team
Airport security	Trial	Airport Police

Table 1 : Operational Activities in Airport Project

In this paper we examine the impact and complexities of operational readiness program in an airport project that was built and operated by government. The choice of airport project for this study is important because of the following reasons:

– Demands in the aviation industry are exponentially increasing which forces governments to construct airports in fast track projects where airports get completed but cannot be operated or it fails on first day of operations.

– Reduce life and safety risks by ensuring all life safety systems and procedures have been fully operationally trialed.

– Ensure high quality services delivery from day one to airport customers and airlines.

– High rate of return to government's investment by providing full and optimal operations from day one.

Figure 3 shows the impact of operational readiness program on operations and how it will assist in ramping up the production capacity and the utilization of mega project's assets in a short time.

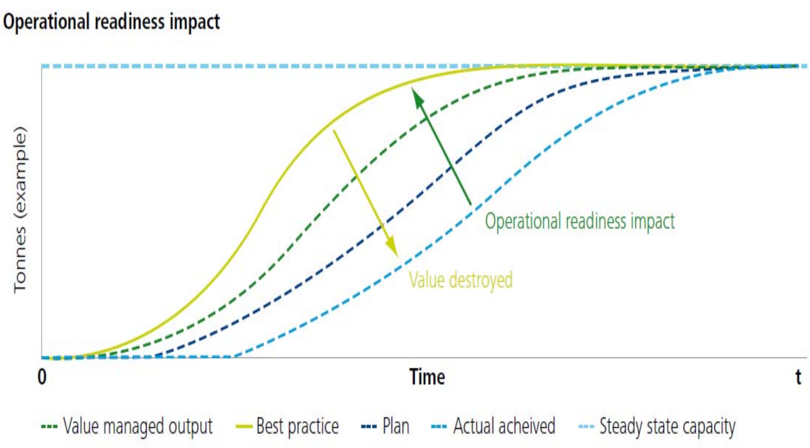

Figure 3 : Operational Readiness Impact (Source:Deloitte (2011))

2. PROBLEM ARTICULATION

Introducing operational readiness program in an airport project might create interruption and delay to contractors working at site because of the activities that need to be carried out by the operational team as well as the rework activities that will arise as a result of these activities. Simultaneously, the operational team will not be able to carry out further operational activities unless the contractor is providing the facilities in the project and complete the rework generated from the operational readiness activities which makes the relationship between the contractor work and operational readiness dynamic and complex.

In many cases, the airport project may reach a good level of completion as per the contractor scope of work but it would not yet be ready for operations and the airport authority need to take a decision on how long they should wait to operate the project after completion. Figure 4 shows the contractor's progress as well as the operational readiness progress in a project and as stated above the operational readiness progress will only start at the last phase of the project life cycle. The graph clearly shows the gap that is created between completion of project and project operations. The purpose of this research is to create a model using system dynamics approach to study how to reduce the gap. It would help to provide a basis for clients to operate the project, and it would also help assist project managers in identifying potential risks.

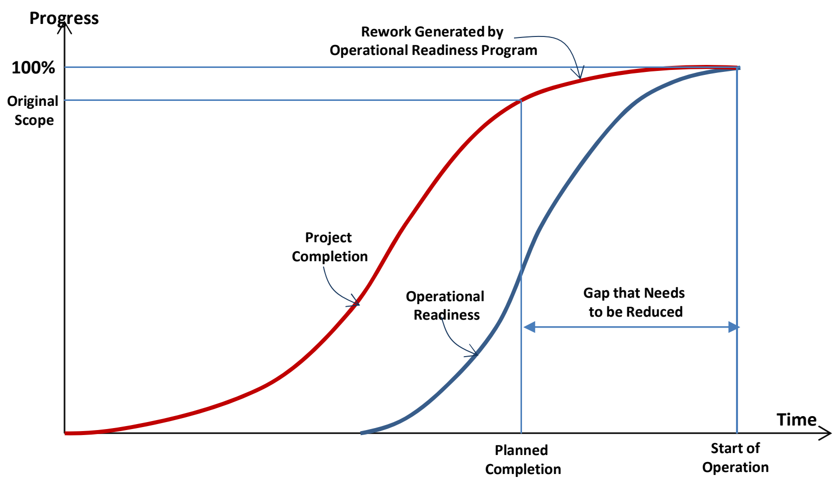

Figure 4 : The Reference Mode

In this paper, a closer attention has been given to some major elements such as the facility availability and human resources competency. The following key variables have been identified and will be used for the dynamic model:

- Rate of construction (task/week)
- Project completions (tasks)
- Operational trials execution (trial/week)
- Training & familiarization execution (T&F / week)
- Operational readiness (scale 0-100) where 0 is not ready to operate with high risk of failure and 100 is fully ready to operate with low risk of failure.

3. DYNAMIC HYPOTHESIS

In order to explain the dynamic hypothesis, a set of feedback loops has been developed (Figure 5) that in order to present an initial understanding of the operational readiness relationship with the project schedule of completion.

The diagram consists of a balancing feedback loop (B1) that shows the interruption of the construction rate by operational trials that will be executed by the operational team, the more the operational trials we conduct the lower the rate of construction will be which in effect will also reduce planned project's completion tasks and in turn the facilities for the operation team to train and trial on will not progress well. Unavailability of facilities will reduce the operational readiness of the project and in turn will not allow further operational trials to execute and vice versa are also applicable. In response to the B1 loop of the dynamic model, a pressure to operate will start to rise as the operation readiness of the project increases which in turn will require operational staff hiring for the trials, system trainings and site familiarizations. Rework cycle will start to erupt as an effect of the operational trials that requires essential changes to suit operational requirements and final mode of operation. The dynamic hypothesis now includes more feedback loops as stated above that have caused more effect and responses. B2 (More Work is Added) loop is the second balancing causal loop that has been created because of the rework that has been generated by the operational trials. Ying & Timothy (n.d, p.3) stated "In complex projects where activities are closely related to each other, the longer it takes to find the mistake, the more additional work can be created in the process of correcting the mistake and the more the total project performance can be degraded." This suggests that B2 loop will definitely help improving the mistakes correction for the value of both contractor and project's owner or client; it's always preferable by the contractor to fix any pending issues before live operations as more formalities and permissions will be required after operations. B3 (creating competency) is the third balancing causal loop that was created because of the availability of the facility in the project, operational staff needs to access the facility and train to become competent and become ready to operate which in turn should increase the level of the operational readiness of the project. R1 (Add more resources), a reinforcing loop as the pressure to operate increases, operation team is required to hire more operational staff to train and familiarize, the increase of operational staff will require more training and familiarization to be conducted on the project areas which in turn will increase job competency in the newly hired staff. The increment in the level of competency of hired staff, level of operational readiness will in turn increase. The causal loop diagram has been further developed incorporating the response to the new actions where the approval time to changes has been added to B2 loop.

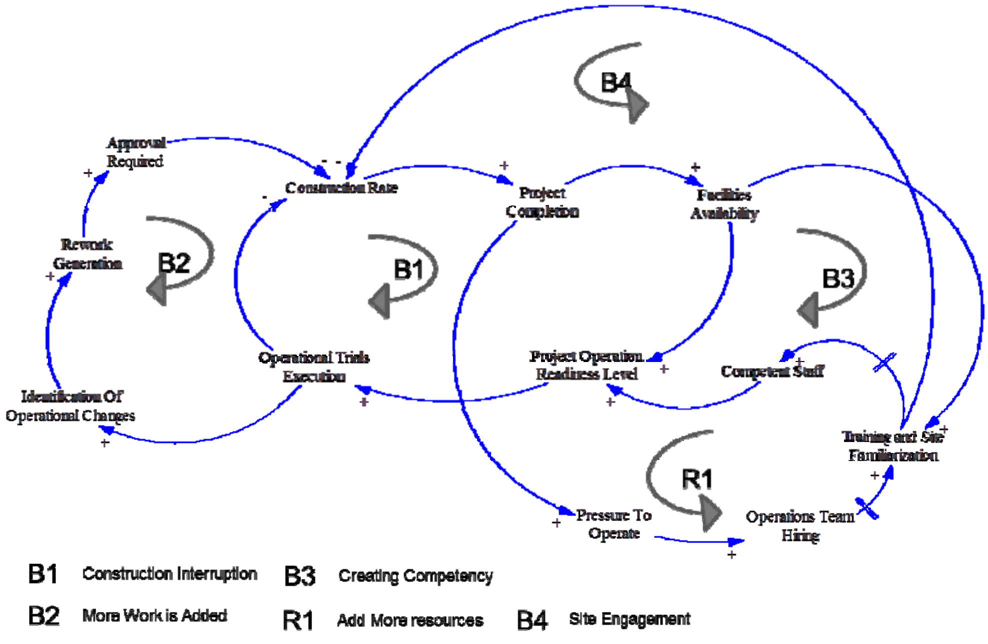

Figure 5 Dynamic Hypothesis

B4 (Site Engagement) is the fourth balancing loop that is created by the staff accessing the site for training and familiarization which interrupt the contractor work rate and delay the completions. The more we have teams for the operations more training and familiarizations will be required to be conducted which in turn will reduce the construction rate and cause delays to the project.

4. SIMULATION MODEL AND VALIDATION

Using the modeling software STELLA, the dynamic hypothesis has been converted to stock and flow diagram. For simplicity and model validation two stock and flow diagrams have been designed. Construction stock and flow diagram as shown in Figure 6, for the model simulation total project tasks of 10,000 has been used.

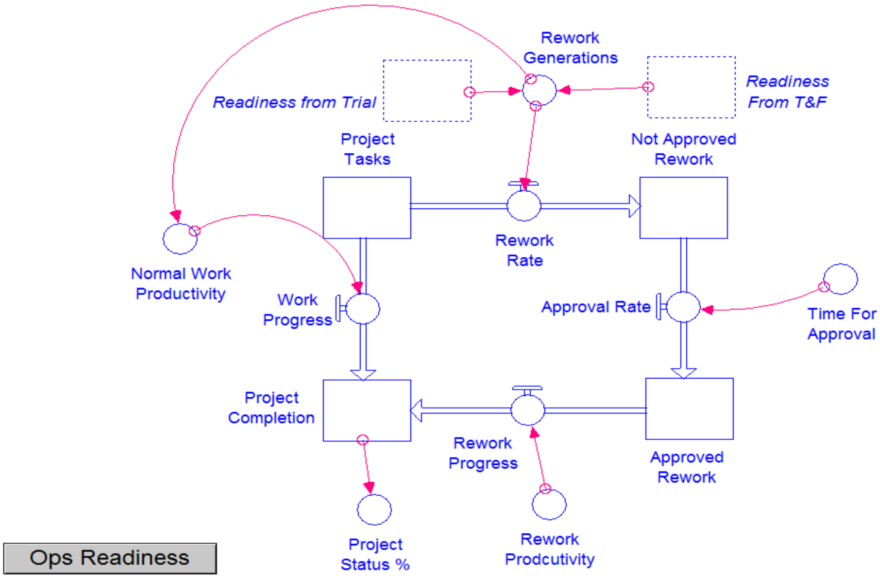

Figure 6 : Construction Stock & Flow Diagram

The diagram in Figure 6 consists of four stocks that contain the construction tasks for a mega project with four flow controllers to control the flow of the tasks until all the tasks are completed. All the tasks shall be processed throw the work progress valve using the normal work productivity which is the cases where we have no interruption to project site and once the project status reach 80% , operational readiness program will start delaying the progress and generate rework that will require approval, and time to complete. The second stock and flow diagram is the operational readiness as shown in figure 7, and in this diagram we have used a measurement of task of readiness that stem from the total readiness activity which is 1000, the number has been selected based on brief discussion with the readiness team from Dubai international airport. The readiness tasks then split to readiness from operational trials or from training and familiarizations.

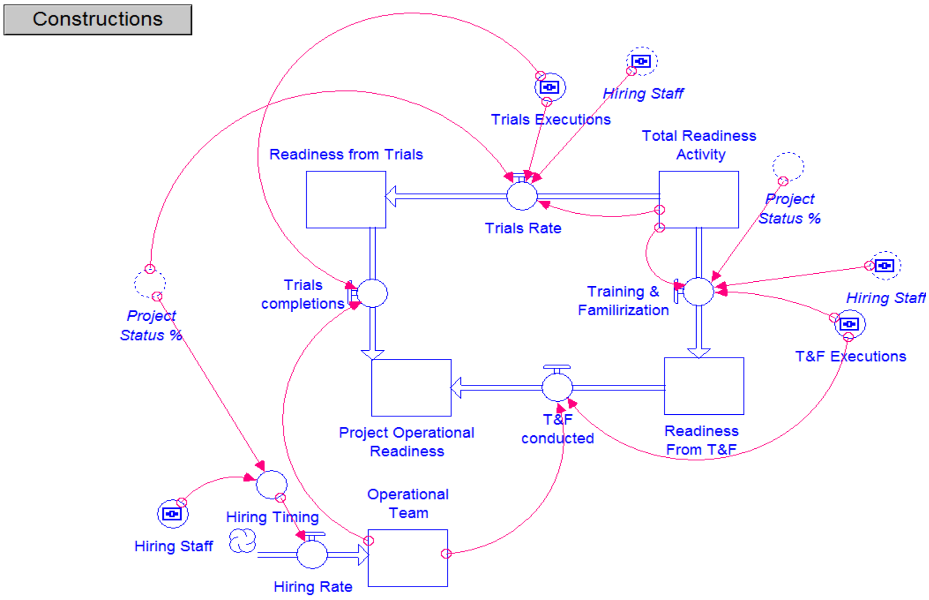

Figure 7 : Operational Readiness Stock and Flow Diagram

In the operational readiness diagram, five stocks has been identified and five flow controllers, the flow of the operational tasks will only be triggered once a construction project status reach 80% to start the training and familiarization and once the project completion reach 90% the trials will be executed. The percentage chosen above was based on discussion with operational team from Dubai international airport. The model has three handles that change model variable for validity and behavioral tests, trials execution rate, training and familiarization rate and hiring rate are the key handles of the model, detail descriptions of the model handles are shown in Table 2.

Name	**Range**	**Description**
Trials rate	0-7 / week	The execution rate of the operational trials on the project facilities can be no trials (0) or full week of trials (7) or any
Training and familiarization	0-7 / week	The execution rate of training and familiarization for the operational team in the project's facilities. It will have
Hiring rate	0-10 / week	The hiring rate of the operational team ranges from no staff hiring (0) to full staff hiring (10) staff per week or any value

Table 2 Model Handles

To validate the model we have set the time range to 200 weeks and assume the normal work productivity to be as 65 tasks / week and set all model handles to zero values, the model has responded with a completion of the project in the 153 week. The results shows that without operational readiness interruption the project will run normally as (Total Tasks/Productivity rate = completion time) which matches the model timing (10000/65 = 153). Another logic validation has also been run for the model with both trials execution and training and familiarizations execution are set to 7 and hiring rate is set to 0, even if you try to run trials and training but you have no staff to execute these activities, there will be no interruption to the project and it should finish on the 153. To validate the model concept and handles input, the trials rate was set to 3 and training and familiarization to 3 and hiring rate to 5, and the result is shown in Figure 8.

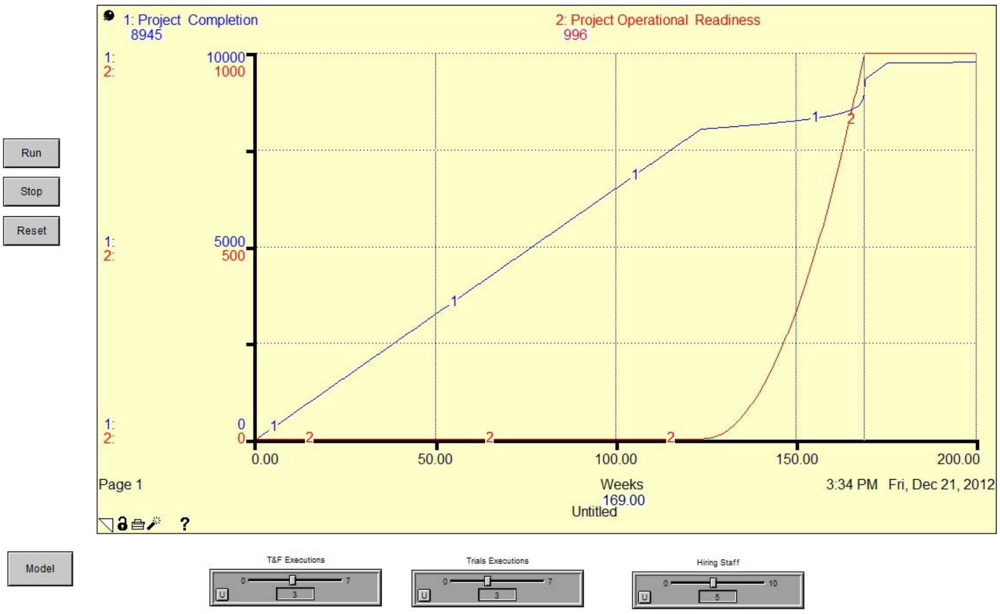

Figure 8 : Model Simulation with Middle Values

From the simulation graph above, we noticed that project progress was slowed down once the operational readiness program was introduced and with the value setting above, the project completion will shift to week 169.The fourth case tested in this model was with trials and training rates set to maximum (7) and hiring remain the same (5), we noticed the time has been extended for one reason that we have engaged and interrupted the project site more with less staff to train and trial which resulted in more time for the contractor to finish as well as for the operational level to reach its desired value. The last test case to run for the model was with all handles variables to be set to its maximum values trials rate (7) , training and familiarization rate (7) and hiring rate (10) which resulted in the graph shown in Figure 10.

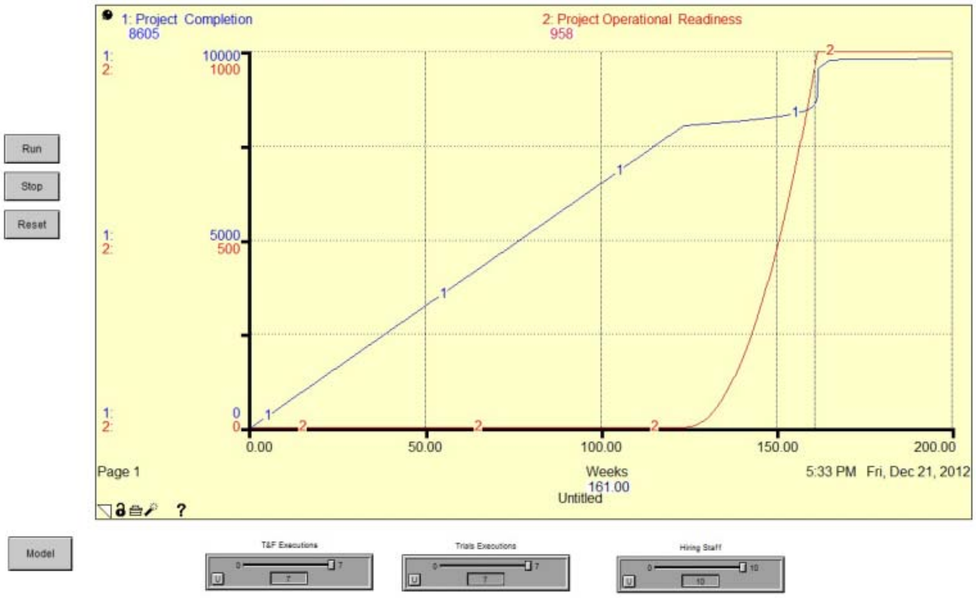

Figure 10 : Full Values on Handles

In the above graph we noticed that completion time (week 161) is the closest time we can get to the ideal project completion time, the above values should help clients set the values for the operational readiness program to be align with the construction program.

5. RECOMMENDATION

Based on the dynamic model results and analysis shown above, the followings are recommended:

– The client should recruit some of the construction and design team to operate the project rather than hiring new staff to reduce delays in hiring and the learning curve of the new staff as it was stated as a problem by (Morgan, 1987) for the project manager at the end of the project. The same has also been recommended by Thompson (1991) in his study where the project's team shall continue to work for the operational phase.

– The client should introduce the operational readiness program in the project's plan to eliminate any resistance or surprises by the project contractor.

– Sensitivity analysis to be conducted with the variable of normal working rate to vary based on the contractor performance over time.

– The model to be simulated for smaller size projects to test their behaviors with operational readiness programs and how it will affect the project's plan.

– More improvement should be applied for the model by adding variables related to other construction factors and delays; it was ignored in this model for simplification.

6. CONCLUSIONS

In conclusion a project can be considered successful when it is fully handed over operationally ready to its final end-users and they make high return value of its investment. To reach a level of operational readiness that will satisfy the project end-users, an operational readiness program shall be introduced at the last stage of the project. This research paper presets a dynamic model that was developed using the system dynamics approach to see the effect of the operational readiness programs. On the basis of the model's simulations certain recommendations have been made to be incorporated to have a smooth transition from construction phase to operational phase with few uncertainties and lower risk.

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A METHODOLOGY FOR ADAPTING HOUSING STOCK USING MODULAR INFILLS

Thomas Bock
Technische Universität München, Munich, Germany, thomas.bock@br2.ar.tum.de

Shabtai Isaac
Ben-Gurion University of the Negev, Beer Sheva, Israel, isaacsh@bgu.ac.il

Abstract

This paper presents a methodology that supports the design of modular housing for the elderly, which can be gradually adapted to their changing needs. The methodology makes use of graphs to represent building information such as user requirements and the design of building components. Graph-theoretic algorithms facilitate an identification of the optimal modularization of the design, in light of the expected replacement rates of components. In addition, graphs can be used to define the process of assembling modules, and of installing them in the building. The proposed approach could alleviate the present hardships for elderly people, who often have to keep moving to new homes as they need more assistance. It can also reduce the costs and waste that are currently involved in adjusting buildings to changes in user requirements.

Keywords: modular construction, design management, automation.

1. INTRODUCTION

Increasing the adaptability of buildings is one of the most effective ways to increase their value, and their users' satisfaction (Manewa, Pasquire, Gibb, & Schmidt, 2009). In practice, most buildings are, however, designed and constructed to suit their use at that time, and their future adaptability is ignored (Beadle, Gibb, Austin, Fuster, & Madden, 2008). Elderly people, for example, often require changes to their physical environment in order to continue performing basic tasks such as bathing and cooking. However, the only way to currently accommodate such changes is often through extensive and expensive refurbishments. As a result, elderly people have to keep moving to new homes as they need more assistance, because their houses cannot be easily adapted to their changing needs. The objective of this research is to develop a methodology that supports the design of modular housing for the elderly, which can be gradually adapted to their changing needs.

An example for such a modular approach is the development of a Robotic Service Wall that is being carried out under a two year funded research project called LISA – "Living Independently In South Tyrol Alto Adige" (Linner, Georgoulas, & Bock, 2012). This wall contains different modules such as robotic actuators, sensors and display screens, in order to enable an Ambient Assisted Living approach. The proposed system can be arranged and re-arranged into various configurations, and can be easily installed in any residence without requiring specific space dimensions (Figure 1).

Figure 1: LISA Robotic Service Wall

The research hypothesis is that an increase in the adaptability of buildings can be based on the systematic separation of building components through modules whose replacement occurs at different intervals. A *building component* is a product that forms a distinct unit, and has its own functional identity, such as window, a partition wall or a beam. A component may contain a number of different materials, but it is usually constructed or assembled in a single process. Components with different replacement rates are currently often connected to each other, and as a result minor changes require the demolition and replacement of many components.

The separation of building parts to allow adaptability has been studied in previous research. In Open Building systems, the 'base-building' and its interior are separated (Habraken, 2003). Most of the previous research has focused on the separation of entire building systems (Hansen & Olsson, 2011; Leupen, 2006). A *building system* is an assembly of components that satisfies particular user requirements, such as the structure, cladding, mechanical systems, etc. Each system is usually designed and constructed by different specialists. Durmisevic and Brouwer (2002) have proposed to extend this approach in order to include the separation not only of entire building systems, but also of individual components within a system, which may have different replacement rates.

We propose to further extend this approach by defining modules, each of which contains several components. These components may belong to different building systems, but have the same replacement rates. The application of such an approach is particularly challenging in the design of large buildings, which contain thousands of different components that are interconnected through various types of relationships. The present research consequently focuses on the development of automated tools that can support the definition of such modules.

2. GRAPH-BASED REPRESENTATION OF BUILDING INFORMATION

The proposed methodology is based on the use of graphs to represent building information, such as user requirements and the design of building components. This information is extracted from databases such as the project brief and Building Information Models (BIM), in which building components are represented as objects. BIM has, so far, mainly focused on the development of objects with complex attributes and their manipulation (Halfawy & Froese, 2005). However, existing data in BIM regarding the relationships between project elements can be used to develop a graph-based model of the project design. Graph-based models are an effective means for representing complex systems with a large number of highly interconnected elements (Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006). The use of graph-based representations of the information contained in BIM has been, so far, sporadic and limited to specific domains such as:

- The representation of rooms and physical connections between building components for building energy simulation (C. van Treeck & Rank, 2007).
- The representation of spaces and openings for accessibility analysis (Eastman, Lee, Jeong, & Lee, 2009).
- The representation of connections between rooms (such as doors and windows) for space planning (Wessel, Blumel, & Klein, 2008).

In a graph-based model of building design, a set of nodes $i \in N$ represents the components in the design, and a set of links $(i, j) \in A$ represent connections between these components. Such connections may be (Figure 2):

a. Direct physical connections, when one component touches or is connected to another component (such as a pipe within a concrete block partition wall)
b. Indirect physical connections, when one component blocks access to another component (such as an HVAC duct above a plasterboard ceiling)
c. Indirect functional connections, when two components satisfy the same user requirement (such as a window and HVAC component which both satisfy a requirement for ventilation)

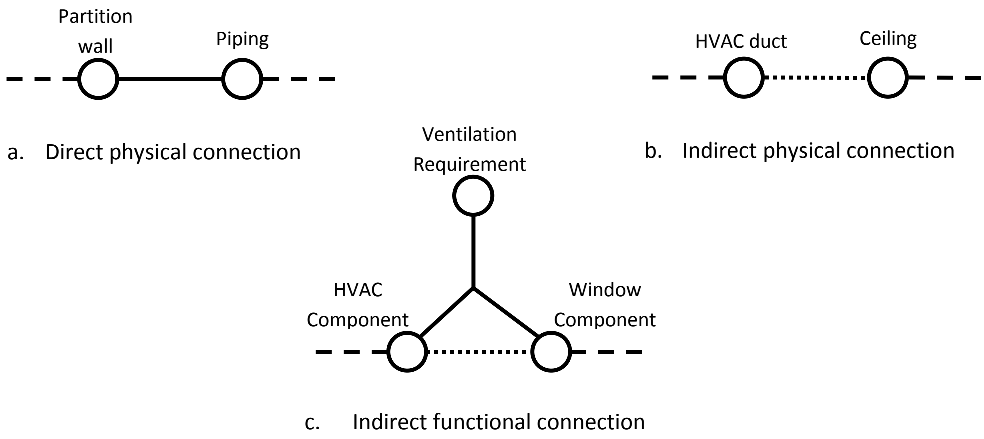

Figure 2: Connections between components

3. METHODOLOGY FOR SUPPORTING ADAPTABLE MODULAR DESIGN

The proposed methodology, supporting the design of modular housing, consists of a number of processes (Figure 3):

a. Representation of the building design and project brief as a graph
b. Ordering the components according to their relative replacement rates
c. Implementation of a clustering algorithm to identify the optimal modularization
d. Adjustment of the replacement rates of intermediary components through the use of buffers in the building design
e. Definition of the assembly and disassembly sequences of the modules

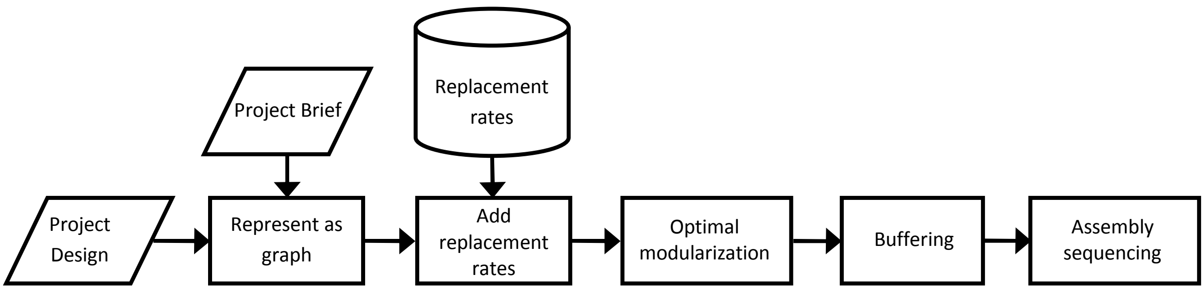

Figure 3: A methodology supporting the design of modular housing

3.1. Ordering components according to their replacement rates

In order to define modules that contain components with the same replacement rates, the components are ordered according to an initial assessment of their replacement rates. The replacement rates r_i are stored in a generic database, and are based on pair-wise comparisons by experts, rather than on an assessment of the actual size of the life expectancies of the systems. It may be clear, for example, that the building structure is likely to last longer than engineering services components, and that some of these components will last longer than finishes and fittings, but it can be very difficult to determine the exact number of years they will last. It is therefore more feasible to use an order topology for such an assessment, instead of a metric topology. In other words, it is possible to assess which component is likely to be replaced sooner, even when it is difficult to assess when exactly this will happen. In addition to allowing the assessment of relative, rather than actual replacement rates, pair-wise comparisons have the advantage of being transitive, i.e.:

$$If\ r_i > r_j\ and\ \ r_j > r_k, then\ \ r_i > r_k$$

3.2. Identifying the optimal modularization

Graph-theoretic measures of topology facilitate an identification of the optimal modularization of the design, in light of the expected replacement rates of components. Specifically, a clustering algorithm is applied to identify groups of components that are connected and have similar replacement rates.

The assessed relative replacement rates r_i are defined as attributes of the building components (Figure 4). A weight a_{ij} is added to link (i, j) to represent the difference between the relative replacement rates of components i and j:

$$a_{\mathrm{ij}} = \left(1 + \left|r_i - r_j\right|\right)^{-1}$$

Here a_{ij} is an entry in the adjacency matrix A of the graph, which is symmetrical (i.e. $a_{ij} = a_{ji}$).

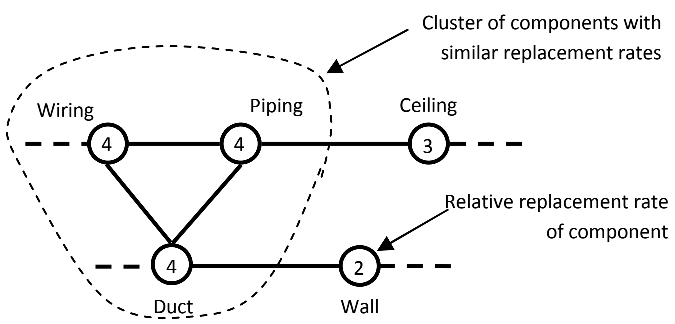

Figure 4: Relative replacement rates of the components

An Iterative Conductance Cutting (ICC) algorithm is applied to identify clusters of nodes in the graph-based model. ICC is a greedy splitting algorithm, which iteratively selects one cluster and splits it into two parts, starting from an initial single cluster. According to Kannan, Vempala, & Vetta (2004), the conductance of a cluster *C*, that is cut to create a subgraph *S*, is defined as:

$$\phi(S,C) = \frac{\sum_{i\in S, j\notin C\setminus S} a_{ij}}{\min(a(S), a(C\setminus S))}$$

Among all cuts that split cluster *C* into two parts, one of minimum conductance is chosen. Clusters are split as long as the value of the conductance is below a certain threshold.

3.3. Introducing buffers in the design

The adaptability of the modularized design can be assessed by calculating the correlation between the assessed replacement rates r_i of components and the betweenness centrality *g(i)* of corresponding nodes in the graph. The betweenness centrality indicates the importance of a node in the organization of flows in the network:

$$g(i) = \sum_{\{j,k\}} g_i(j,k)\,,$$

where $g_i(j,k)$ equals 1 if the shortest path between nodes *j* and *k* passes through node *i* and 0 otherwise (Cohen & Havlin, 2010). The rank correlation $\rho(g,r)$ of (g,r) should be high and negative. If the correlation is too low, this implies that the replacement rates of specific components with a high betweenness centrality are not low enough. Such components serve as supporting frames or intermediary components that connect the different modules. Their replacement rates can be reduced through the use of buffers in the design. Such buffers are applied by designing components with a capacity larger than that required in order to fulfill the present user requirements in the building program. This extra capacity can be used in the future to absorb the impact of changes in user requirements, without requiring a change in the components.

3.4. Definition of the assembly and disassembly sequences of modules

The graph-based model can be used to automatically define the sequence in which components are assembled into modules, and in which the modules are installed in the building. This is necessary in light of the large variety of different kinds of modules that can be expected. There is consequently a need to automate their assembly process, in order to prevent lengthy and costly manual processes. An automated definition of the assembly process could also facilitate a robotic assembly of the modules (Bock, 2007). The sequence in which components are assembled into modules should correspond to the node degree k_i of the components. In order to determine these sequences, the disassembly process is divided into phases d, where the disassembly phase of a node is equal to its degree k_i:

$$d_i = k_i$$

A component with a high node degree (i.e. with more connections to other components) should be assembled earlier, and disassembled later. The required assembly sequence is therefore the inverse of the defined disassembly sequence.

4. CONCLUSIONS

This paper presents a methodology to support the design of modular buildings that can be adapted more easily throughout their entire life-cycle, in order to allow for changes that are required. Elderly people, whose requirements change dramatically in a relatively short time, may in particular benefit from this approach. The methodology is being implemented in the case-study of the Robotic Service Wall project called LISA (Linner, et al., 2012).

In the proposed methodology, a clustering algorithm is applied in order to identify the optimal modularization of a design, taking into account the expected replacement rates of components. The identified modules may satisfy different user requirements, belong to different systems or trades, and be composed of different materials, as long as the components they contain have similar replacement rates.

Additional graph-theoretic measures are used to support a modular adaptable design. The betweenness centrality of nodes is measured in order to ensure that the replacement rates of highly connected components are not too high. The sequence in which components are assembled into modules is identified according to the node degree of the components. Thus, the proposed methodology demonstrates the benefits of the use of graph theory in construction management research.

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TEACHING CONSTRUCTION MANAGEMENT: DEVELOPING E-LEARNING MATERIALS

Orsolya Bokor
Szent István University, Ybl Miklós Faculty of Architecture and Civil Engineering, Budapest, Hungary, bokor.orsolya@ybl.szie.hu

Miklós Hajdu
Szent István University, Ybl Miklós Faculty of Architecture and Civil Engineering, Budapest, Hungary, hajdu.miklos@ybl.szie.hu

Abstract

Szent István University's Ybl Miklós Faculty of Architecture and Civil Engineering is developing eLearning materials for Construction Management BSc students. The project has been being carried out within the framework of the New Széchenyi Plan run by the National Development Agency. It started in March 2012 and is expected to end in December 2013.

Four great areas are involved: Construction Management, Construction Technology, Building Constructions and Technical Documentation. Our goal is to create study materials that are modern, up-to-date and put emphasis on practical issues. The materials are complete with numerous figures, tables, videos, even interactive ones and countless examples and tasks in order to facilitate better understanding.

In this paper, the project as a whole is discussed and all thirteen subjects are described. The structure and elements of the materials are dealt with in detail. Moreover, the challenges faced by the project team and their possible solutions are presented.

Keywords: construction management, construction technology, education, elearning.

1. THE PROJECT

Our faculty, Szent István University's Ybl Miklós Faculty of Architecture and Civil Engineering – hereinafter referred to as Ybl – has been taking part in a Social Renewal Operative Program within the framework of the New Széchenyi Plan run by the National Development Agency. The project started on 1 March 2012; and it is going to end on 31 December 2013. 95% of the budget is subsidized; it is co-funded by the European Social Fund. The aim of the project is to develop e-learning teaching materials for 13 subjects of a new Construction Management BSc program.

These 13 subjects – Construction Management 1-4, Construction Technology 1-4, Building Constructions 1-4 and Technical Documentation – would give the core of this new program that is hopefully going to be launched soon, since it is really essential to train experts who know the technical, as well as the legal and economic sides of the construction projects, and who can also perform management duties. Today this kind of program is absent in Hungary, although it is very common in, for example, Europe and the US.

Many people are involved in this project. Most of the materials are written by teachers from Ybl. Some of them are put together by teachers from the Budapest University of Technology and Economics. In some cases, experts from the construction industry are of help.

Every material is in Hungarian, however, the Construction Management 1-4 lessons are going to be translated to English as well.

2. THE SUBJECTS

Technical Documentation is the first one that the students are going to meet, as it will be taught in the first semester. Its main aim is to get the students acquainted with the basic requirements of technical drawings, the usual notations and symbols. As construction managers, they will not make these drawings, however, their jobs will demand them to be able to read them and to know what a proper documentation should consists of.

The other 12 subjects are going to be taught parallel to each other starting from the second semester. While the Building Constructions subjects show the students all the structures and works that they can see in their professional lives, Construction Technology is responsible for explaining them how these can be constructed, how the different works have to be performed. Building Constructions 1 deals with earthworks, foundations, insulations and public works. In the next term, students continue with load-bearing structures, monolithic and prefabricated structures, masonry works, stairs and elevators. Building Constructions 3 introduces flat and pitched roofs, cladding and doors and windows. Lastly, students are familiarized with curtain walls, partition walls, floor structures and finishes and building services engineering. In accordance with the above-mentioned topics, Construction Technology 1 gets the students acquainted with the preparation for the on-site works, demolition works, earthworks and foundations concentrating on the machinery used and the steps of the different technologies. The same approach is true for the monolithic and prefabricated concrete, masonry and roof structures taught in the third semester. Construction Technology 3 deals with the construction of flat and pitched roofs, non-load-bearing external and partition walls. Finally, scaffoldings, cladding, floor and wall finishes, doors and windows are discussed from a technological point of view.

Construction Management is also taught for four semesters. The first one gives an introduction to the world of investments. The various stakeholders and the entire process are also described in detail. Moreover, students are given a sneak peek into the following three semesters. In order for them to see the connection between their subjects better, the relationships between scheduling and site layout design is also discussed. Construction Management 2 deals with the construction budget. Different Hungarian and European norm databases, cost estimation methods and practices are introduced. Next, the students get acquainted with various scheduling techniques from the traditional to the most modern ones together with resource planning. Construction Management 4 looks over the construction process from the point of view of the documents that have to be collected and issued in this period of the projects. Furthermore, safety measures and quality assurance are also discussed.

3. THE MATERIALS

In case of each subject an average of 14 lessons are written corresponding with the number of lectures in a semester. This way the titles of the lessons constitute the curriculum of the given subject for one semester. This also means that the contents of one lesson should not exceed the time limit of one lecture, which is usually 90 minutes. On the other hand, the materials have to contain extra information for those who are interested in the subjects and extra examples and task for the students to be able to prepare for the tests and exams.

Each lesson is divided into five chapters, and these are made up of pages. The website-like appearance provides easy navigation between the various parts. See, for example, the top right corner of Figure 1. The little squares represent the pages of the chapter. The orange one indicates the current page.

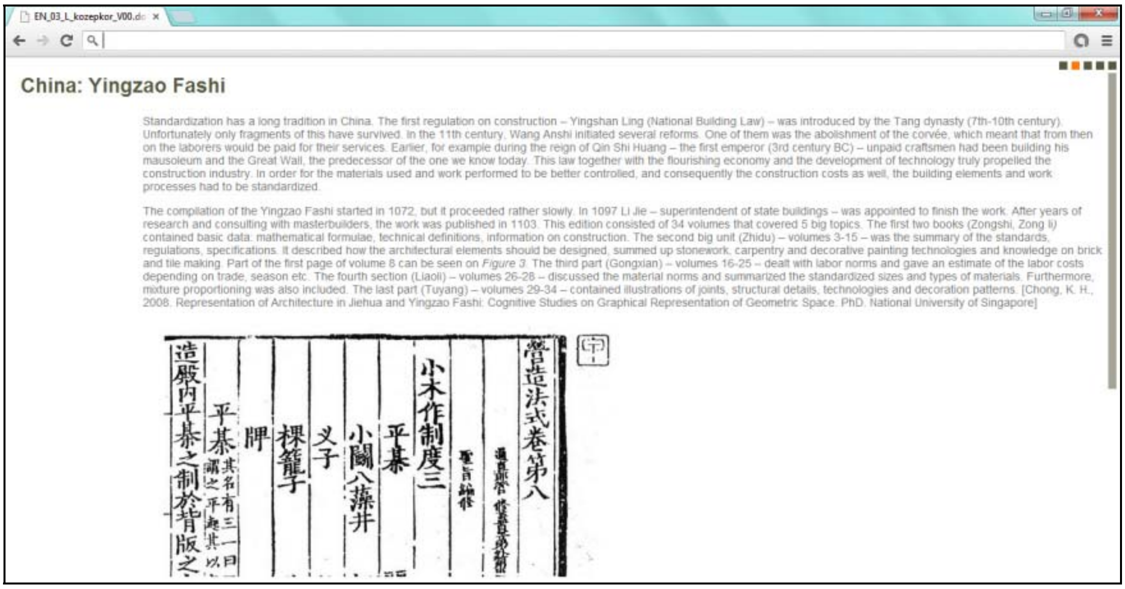


Figure 1: One page from the History and Development of Cost Estimation (second lesson of Construction Management 2)

Every lesson is made up of different elements. These are the following: text, figures, interactive videos, non-interactive videos, tasks. The planned amount of each element is given in case of all lessons.

Naturally, the text is the most essential part of the study materials. Being digital means that even the text could be enhanced. The most important definitions appear in pop-up bubbles after clicking on the words. Also links can be added to the text. These can be divided into two groups. To the first one belong those links that point to a certain part of another lesson either of the same or of another subject, thus enabling the connection between the lessons. The other group includes those links that lead to websites, where students can find extra information in the form of texts, figures or videos etc.

Figures can include many different types, as well. There can be tables, photos, sketches created by the authors or obtained from external sources. It is especially important in case of the Construction Technology subjects to illustrate the text with figures. Sketches can show the theory, while the photos shot at various construction sites demonstrate the practice.

Interactive and non-interactive videos can also appear in the materials due to the fact that they are going to be accessed through the internet and not on paper. The difference between the two types is that in case of interactive videos students are more involved; they can choose what they would like to see. These videos can serve different purposes. In case of Building Constructions and Construction Technology, there are 3D videos, where the point of view can be changed and the model can be looked at from all angles. There is, for example, a video that shows the construction of a roof structure step by step. In case of Construction Management, videos can also demonstrate a process, like how to perform the time analysis of a CPM network, summarize the text and figures of the lesson, for instance to sum up all the data a table in a norm database contains, or provide additional information on a topic discussed, for example, display pages from old books on how to calculate the construction costs.

Tasks can be found at various places in the lessons. They are usually at the end of the chapters or lessons. They can be of different types. Some of them are multiple choice questions with one or many good solutions. If the right answer is ticked, the smiley is going to smile (Figure 2), if not, it gets sad-angry (Figure 3).

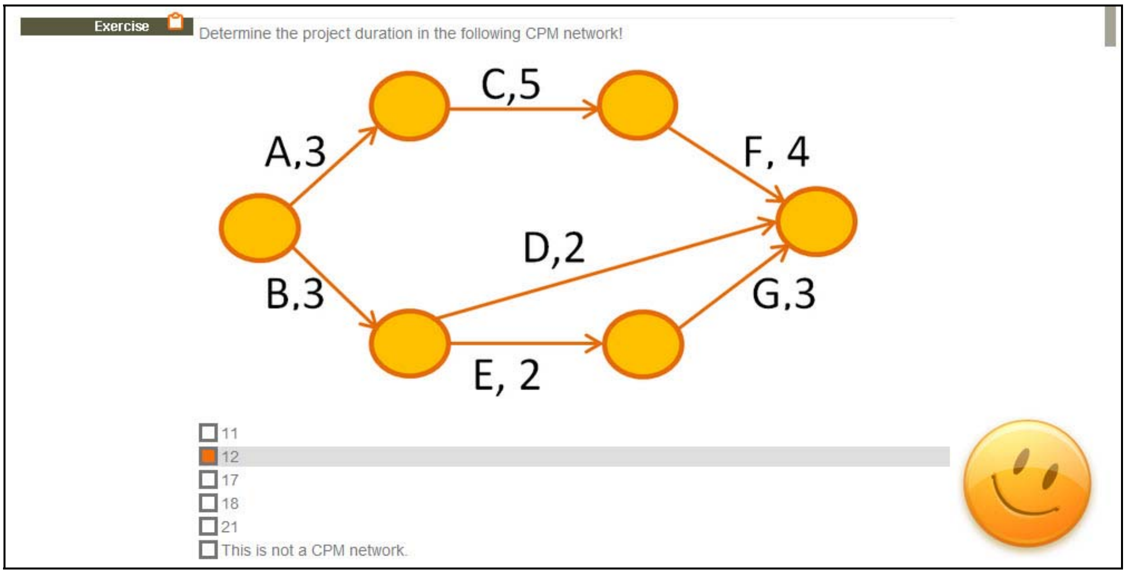


Figure 2: Smile for the right answer

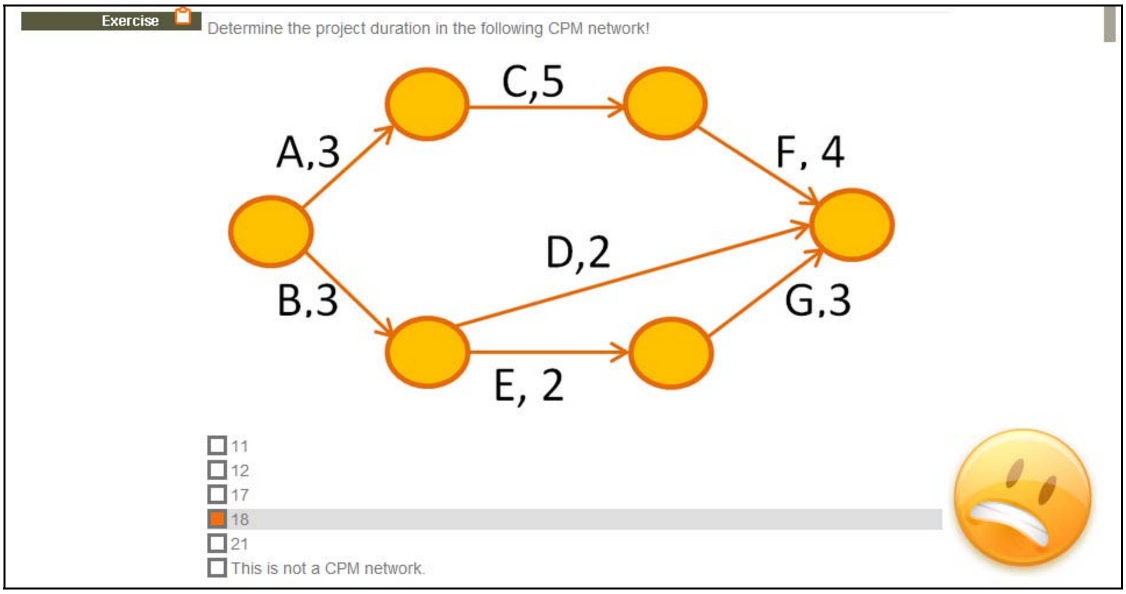


Figure 3: Angry face for the wrong solution

If more than one answer has to be checked for the right solution, the face only appears when all of them are ticked. (See Figure 4.)

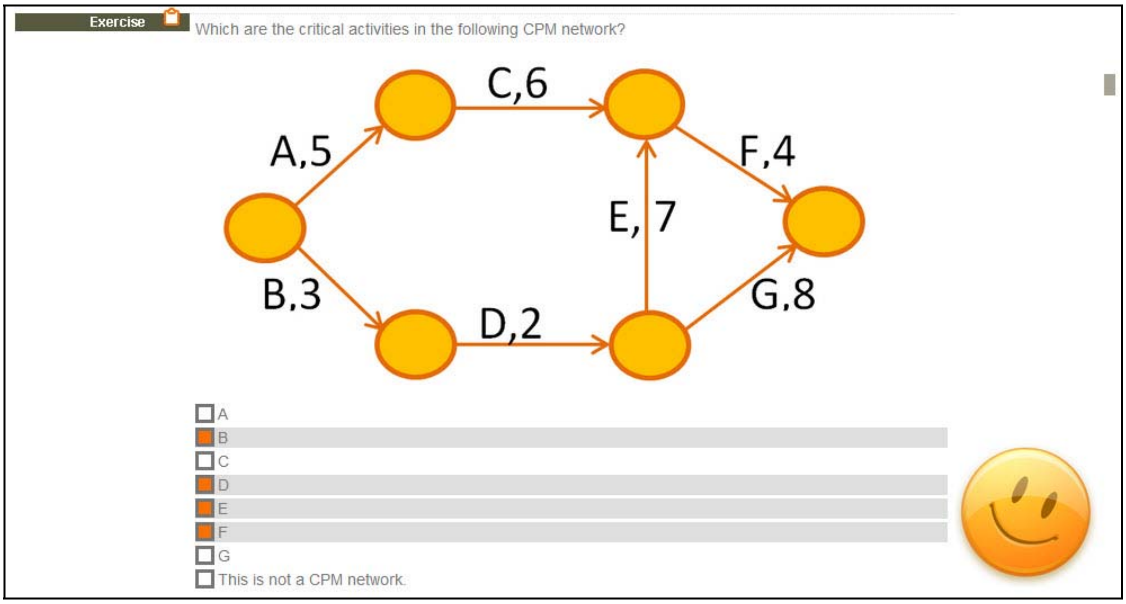


Figure 4: All right answers have to be checked

Some tasks require calculations. In case of one half of these tasks, the solutions are given, and can be reached by the students when they would like to see them. In case of the other half, the answers are not provided.

No matter what type the exercise belongs to, they all serve the same purpose. They measure the students' level of understanding. This way they would know what parts of the lesson they have to go through again.

Every lesson ends with a bibliography. This, on the one hand, is important, because we do not want to commit plagiarism, so we always properly apply references. On the other hand, we could add extra sources of information, as well, for students who are interested in certain topics.

4. CHALLENGES

In spite of the fact that the project is not over yet, we have already faced lots of challenges. The first one was to create the curriculum of the subjects, thus the titles of the lessons. It was important to include all essential topics; however, there was no way to contain everything. We had to bear in mind that these materials are for BSc students, therefore everything had to be tailored to their level. This is also true for each lesson. As mentioned before, every lesson corresponds with one lecture in a semester, thus the length of one lesson is limited by this fact. On the other hand, additional information can be provided for students who are more eager to learn. Moreover, the large number of tasks helps everyone prepare for the tests and exams.

Another issue is uniformity, both in appearance and language. The first aspect is the easier of the two. Every author uses the same template; furthermore, an editor creates the final shape of the materials. Finally, our colleague responsible for the IT solutions translates the Word files into webpages. The second one is a little more difficult. We agreed at the beginning that we would try to keep the tone informal. Again, due to the fact that we are writing these materials for BSc students, who are usually in their late teens, early twenties, we would like to adapt to that. This endeavor is what explains the great amount of figures and videos, as well. Firstly, owing to the fact that we are in the 21st century when young people do not necessarily like to read and when everything is accelerated. And secondly, because we believe that engineers (now including construction managers), even prospective ones, are “visual” learners. Thirdly, due to the fact that sometimes it is easier to explain something with a sketch, figure or video, than with words or formulae. For example, how to build a prefabricated concrete hall or how to perform the time analysis in a PDM network.

Moreover, it is imperative for every lesson to contain the most up-to-date information. This is achieved by thorough research, discussing certain topics with experts working in the construction industry. The two project managers, who are also industry professionals, overlook the project in this sense as well. They are also keen on the practicality aspect of the materials. Since Ybl traditionally trains professionals who are going to work for contractors, rather than design firms, the introduction of the practical application of the theory has always been top priority.

5. RESULTS, APPLICATIONS

As stated before, the goal of the project is to develop study materials for Construction Management BSc students. However, these lessons can be very well used in case of Architecture and Civil Engineering students, who we are already teaching. Also, we hope these could be used by our part-time students, and they can be helpful for distance-learning ones as well.

To comply with the new requirements of the 21st century, the materials can be accessed via the internet from anywhere in the world. Despite this and the fact that these materials are enough for a five (best grade in the Hungarian educational system), they cannot fully substitute the traditional way of studying, attending lectures. Firstly, because students learn easier when they use many of their senses (sight, hearing etc.), and secondly, owing to the teacher-student and student-student interaction that can happen in school, which all add to the learning experience. At Ybl, we are already using a kind of e-learning system, where students can find lecture and practice presentations, upload their homework assignments, write tests etc. Here they have the opportunity to leave comments in the forum, which enables the above-mentioned interactions. This means that later a couple of additional functions can complete the study materials.

Even though the end of the project is December 31, 2013, we plan on updating the lessons from time to time, and complement them with new technologies, techniques and methods.

Some of them also refer to laws and regulations, which are changing rapidly; therefore these parts have to be updated too.

Another part of the project is the education of teachers. It means that we have weekly meetings, when a few lessons are introduced to the others. This practice has many advantages. One is that this way everyone gets acquainted with all the topics of each subject. On the other hand, the colleagues can share their objective opinion and provide feedback, thus enabling the author to make the given material better. In brief, we can learn from each other and teach each other at the same time.

In conclusion, it can be stated that we are striving for making up-to-date and practical study materials complying with the requirements of the 21st century for the new Construction Management BSc students, while hoping they could also be well used in case of other programs.

APPLYING LINEAR SCHEDULING FOR SAFETY PLANNING IN BUILDING PROJECTS

David Buskila
Ben-Gurion University of the Negev, Beer Sheva, Israel, buskilad@bgu.ac.il

Shabtai Isaac
Ben-Gurion University of the Negev, Beer Sheva, Israel, isaacsh@bgu.ac.il

Abstract

Many accidents occur on building sites due to teams working in proximity to each other or to dangerous objects. The objective of this paper is to study the application of linear scheduling for work space resource leveling, while simultaneously ensuring the safety of workers. In order to take into account the planned construction processes, paths along which teams of workers move on the site and in the building are defined and represented in linear scheduling charts. Required minimal distances are defined between every two teams, and between teams and dangerous objects. The distances between teams, and the objects that should be avoided, are then explicitly represented to ensure that the predefined minimal distances are adhered to at any time. When multiple work-paths are planned on the site, the points where the paths intersect are identified to ensure conformance to the required distances between teams using different paths. The execution of the plan can be efficiently monitored in real-time, since only the locations of the teams on predefined paths are required.

Keywords: linear scheduling, safety planning, building projects.

1. INTRODUCTION

Adequately training construction workers for their tasks is often cited as one of the most effective ways to improve safety on construction sites (Sawacha, Naoum and Fong 1999, Toole 2002). However, due to the presence on construction sites of multiple teams carrying out different activities, workers of one team are often exposed to dangers posed by the activities of other, unrelated teams (Sacks, Rozenfeld and Rosenfeld 2009). Thus, the different methods and models available to train and manage workers in order to reduce the risks posed by their own activities, are not sufficient in order to prevent them from being exposed to risks caused by the activities of other teams. Such risks can be prevented by defining *minimal distances* that need to be adhered to at all times, between two teams, or between a team and a dangerous area (due to the presence, for example, of certain equipment). The definition of such distances, and the adherence to them, is complicated by the fact that the construction process involves the movement of teams along certain paths on the site. Such *movement paths* can be both horizontal and vertical. For example, a team can follow a spiral movement path on different floors of a multi-story building.

The definition of minimal distances between teams of construction workers for safety, and of paths along which the workers move on the site in order to carry out their activities, involves *work space resource leveling*. The objective of work space resource leveling is to ensure that the space on the construction site is maximally utilized, with no dangerous overlaps between the areas in which different teams work, but also no unnecessary gaps between them that reduce productivity (Akinci et al. 2002, Zhang et al. 2007). A novel methodology is proposed here for such work space resource leveling. In this methodology, linear scheduling methods are applied in order to ensure construction worker safety.

2. METHODOLOGY

Linear scheduling (also called line-of-balance, time-location or location-based scheduling) is a visual technique that uses lines in diagrams to represent the activities carried out at specific locations on a site (Jongeling and Olofsson 2007, Russell et al. 2009). In these diagrams, the points on one axis represent repetitive physical sections of the building being constructed, such as areas, floors, or apartments. The second axis represents time, so that the section of the building in which an activity is carried out at any moment can be identified in the diagram. One of the main principles of linear scheduling is synchronization: planning the schedule so that different activities are executed at similar production rates. A synchronized linear schedule can be identified by parallel lines that show a constant time buffer between different activities.

In the present study, the linear scheduling diagram is modified so that the location-axis shows the distances between points on the movement paths of teams on the construction site, rather than a repetitive section of the building (Figure 1). In this, it is similar to linear methods used for scheduling infrastructure projects, such as roads or railways.

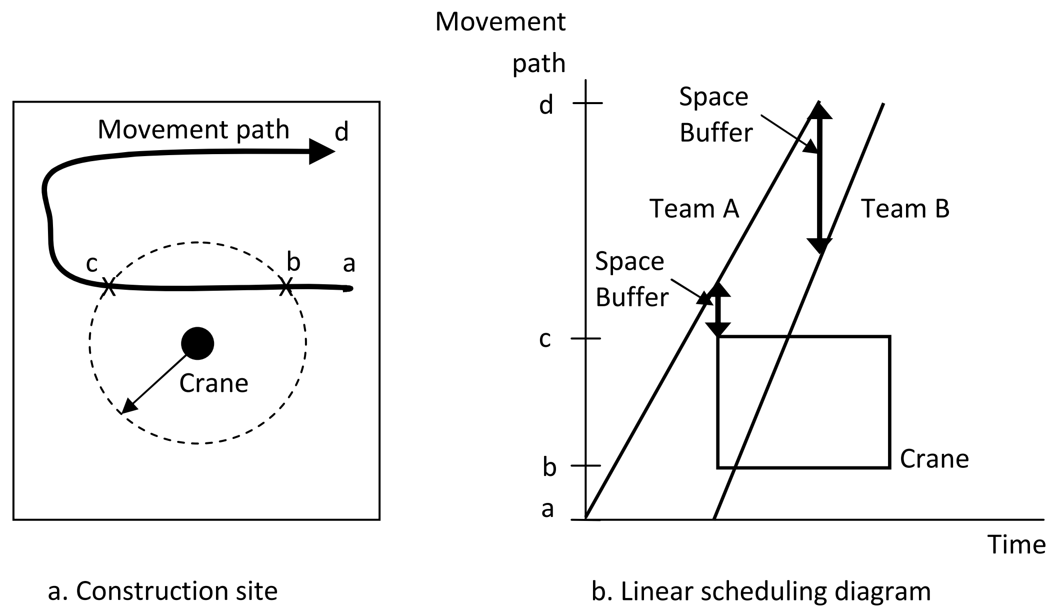
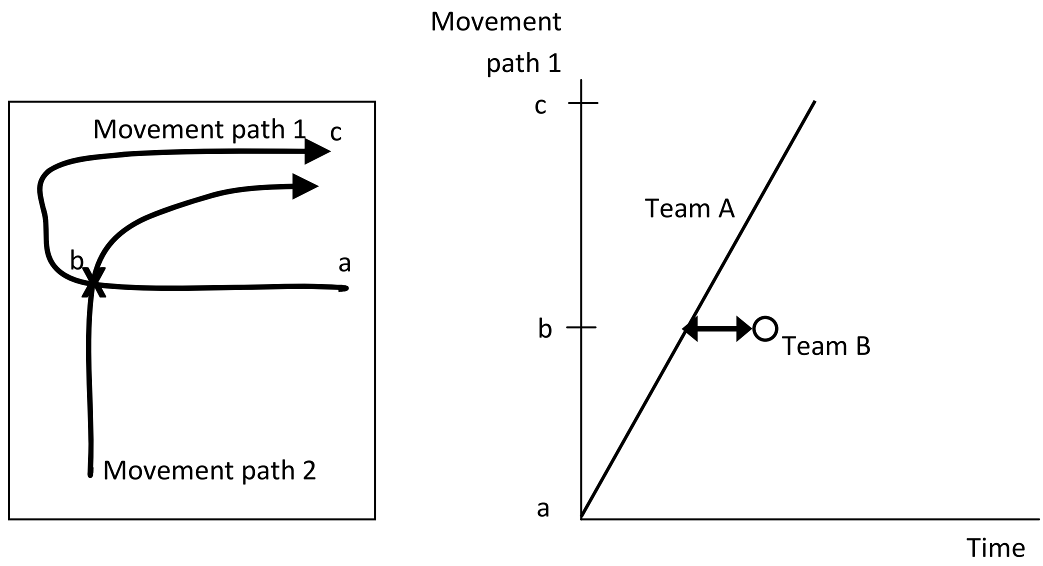


Figure 1: Application of linear scheduling diagram for safety planning

The diagram is used to plan the work of the different teams, while ensuring their safety. A team may carry out different activities on a single path, represented as a single line in the diagram. The representation of movement paths in the linear scheduling diagram enables the planning of exact space buffers between the teams (and not only time buffers between activities), in order to reduce safety risks , and facilitate work space resource leveling.

In addition to the representation of teams of workers that move on the site, certain static objects are also represented in the diagram, when minimal distances have to be kept between those objects and teams of workers. For example, workers may need to work at a certain distance from a crane, or from a storage area with flammable material. Such objects are represented in the diagram as boxes (Figure 1). The height of the box represents the portion of the movement path occupied by the object or its work area, and the width of the box represents the duration for which the object remains on the site. A space buffer is planned between the object and specific teams that are simultaneously working on the site.

Different teams may move along different paths on the site, yet they may still affect each other at specific points of time, when these paths intersect. Different diagrams are used to separately represent each movement path, and the team or teams working on it. When multiple work-paths are planned on the site, the points at which they intersect are identified on map of the site (Figure 2). These points are then marked on each of the path diagrams. Once the work of the different teams has been planned, the times at which they reach the path intersection points are compared to ensure sure that teams using different paths are not within minimal distances from these points at the same time.



a. Construction site b. Linear scheduling diagram

Figure 2: Intersection of different movement paths

Once the movement paths of different teams have been planned using the above-mentioned diagrams, these diagrams need to be updated according to the actual progress on the site, which may deviate from the plan. While the monitoring and control aspects of the proposed methodology have not been addressed yet in this study, it is likely that readily available and relatively inexpensive real-time location technology such as RFID can be used to identify the precise locations of teams on a path. Since the objective here is only to monitor and update the plan, in order to ensure that the work is proceeding accordingly, it is assumed that the teams work along the predefined paths. The location data therefore does not have to be very precise (i.e. not sub-meter) or very frequently updated (i.e. every second). It can rely on simple RFID readers located on the paths.

To summarize, the proposed methodology includes the following steps:

1.Definition of minimum required distances between two teams or between a team and an object on the site

2. Planning of the movement path of each team on the site

3. Planning of space buffers between teams and static objects that are located on their path

4. Planning of space buffers between different teams that work on the same path

5. Planning of space buffers between teams at the intersection points of different paths

The robustness of the methodology depends on the definition of the minimum distances according to which the space buffers are planned. Section 3 therefore describes in detail a proposed method for the calculation of these distances.

3. CALCULATING MINIMUM REQUIRED DISTANCES BETWEEN ELEMENTS ON THE SITE

In order to define the minimum required distances between two elements such as workers, equipment or material on the site, the properties of each element are analyzed. Those properties that may affect the risk of accidents occurring are identified. Pairs of properties are defined, so that property 1 of element A is controlled by property 2 of element B. For example, the risk of a welder A causing a fire is controlled by the degree of flammability of material B; the risk of equipment C injuring worker D is controlled by the level of his experience working in proximity to that equipment, etc. The analysis of these different interacting properties of two elements facilitates the calculation of the maximum distance at which they may affect each other, and the consequent minimum distance that must be kept between them in order to prevent accidents.

Once the pairs of properties are identified, the elements are given a rating on a 1-5 point scale by experts for each property. The rating represents the level at which the property cause the element to affect or to be affected by its surroundings (1 point representing a minimum level and 5 a maximum level). For each element, ratings are defined in a matrix of *j* pairs of controlling and controlled properties that have been identified:

$$[A] = \begin{bmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \\ a_{13} & a_{23} \\ \vdots & \vdots \\ a_{1j} & a_{2j} \end{bmatrix}, [B] = \begin{bmatrix} b_{21} & b_{22} & b_{23} & \dots & b_{2j} \\ b_{11} & b_{12} & b_{13} & \dots & b_{1j} \end{bmatrix},$$

where $[A]$ is the matrix for element A, and a_{ij} is the rating given for property *i* out of *j* pairs of properties. In addition to the representation of the properties of elements in matrices, particular conditions on the site, such as the simultaneous presence of workers belonging to different subcontractors, are represented through coefficients A_l, representing the relative increase in distance required under such conditions.

In order to calculate the minimum distance between two elements, their matrices are multiplied:

$$MAT = [A] \cdot [B]$$

The value of the matrix is defined as the sum of its elements:

$$MAT_{value} = \left(a_{11}b_{21} + a_{21}b_{11} + \dots + a_{2j}b_{1j}\right)$$

Thus, the lowest possible value of 2*j for* MAT_{Value} is obtained when all the properties of both elements are rated "1". In such a case, it is assumed that no distance has to be kept between the elements. The highest value of 50*j* for MAT_{Value} is obtained when all the properties of both elements are rated "5". In such a case, a minimum distance *y* that has been defined for conditions of maximum risk has to be kept between them:

$$MAT(min)_{value} = 2j \Rightarrow f(MAT(min)_{value}) = 0$$

$$MAT(max)_{value} = 50j \Rightarrow f(MAT(max)_{value}) = y$$

Any value in between these two extremes that is obtained for MAT_{value} can be converted into the minimum required distance through the following function, assuming that the change in risk is linear (Figure 3):

$$Minimum\ Distance_{initial} = f(MAT_{value}) = \frac{y}{48j} MAT_{value} - \frac{y}{24}$$

This distance is multiplied by coefficients A_l, representing the relative increase in distance required under *l* particular conditions on the site:

$$Minimum\ Distance_{final} = \prod_{l=1}^{n} A_l\, f(MAT_{value})$$

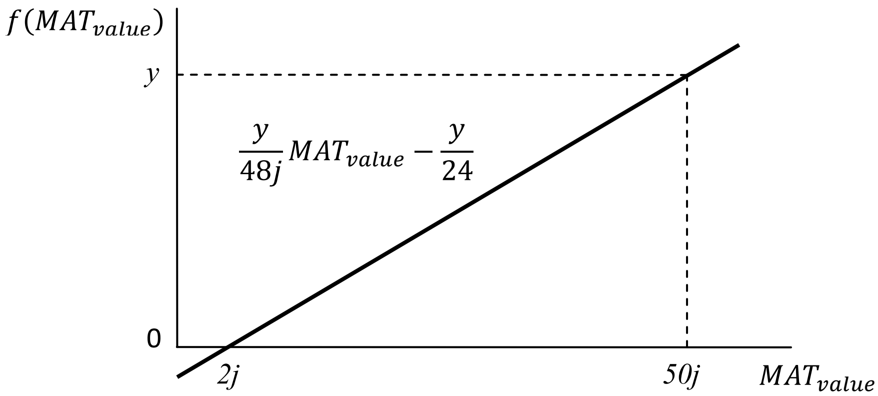


Figure 3: Calculating the minimum distance between two elements

4. CONCLUSIONS

This paper presents a proposed methodology that applies linear scheduling methods for work space resource leveling, while ensuring the safety of workers. The paths along which teams of workers move on the site are defined and represented in linear scheduling charts. A method is presented for calculating the required minimal distances that are defined between pairs of elements on the site. It is currently being implemented in a real-life case study.

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THE APPLICATIONS OF BIM MODEL IN DESIGNS CHECKING

Yi-Jao Chen
University of Kang-Ning, Tainan, Taiwan, yjchen@ukn.edu.tw

Chia-Wei Huang
National Cheng-Kung University, Tainan, Taiwan, n66994502@mail.ncku.edu.tw

Chung-Wei Feng
National Cheng-Kung University, Tainan, Taiwan, cfeng@mail.ncku.edu.tw

Yu-Ren Wang
Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan, yrwang@cc.kuas.edu.tw

Abstract

The quality of building designs has major impact on the construction works, safety, and functionality of the building. However, compared with the construction management in construction phase, most projects have lacked of an effective design checking method, which may frequently leads to the interference with rules and regulations, the conflict with design content, design modification, etc. These imperfections might result in a rise of construction cost, schedule delay, and severely affect the quality and safety of the buildings. To improve the above-mentioned defeat, this study will develop an automated checking method to enhance the quality and efficiency of designs check. This study processes an IFC-based information model that employs BIM technology to assist the checkers of the building designs to access information according to their needs. The BIM model will allow both automatic parametric generation of designs that respond to various criteria and the computer-interpretable models and automated checking of designs after the 3D object modeling buildings are generated. In addition, an automated checking framework will be developed to examine the feasibility.

Keywords: building designs checking, BIM, design rules, information integration.

1. INTRODUCTION

Architectural design determines whether building construction can proceed smoothly as well as the subsequent safety and functionality in its usage. Therefore, design checking is as important as project supervision during the construction phase. However, compared to the management of the construction phase, less attention is paid to quality checking in the design phase of a construction project. In practice, the majority relies on the long-term accumulated experience of examiners in design checking. Manual checking is not only difficult, but it may also easily become a mere formality, and many mistakes often occur, including conflicts with statutes or regulations, conflicts in design, implementation difficulties, and changes in design. These mistakes not only cause project cost overruns and delays but also have a more serious impact on the overall quality and safety of the building.

In recent years, with the rapid development of the building information model (BIM) (Barlish and Sullivan, 2012), many advanced countries have used the BIM in architectural design checking, such as CORENET (CORENET, 2008) developed in Singapore, SMARTcodes (Conover, 2007) developed by the International Code Council (ICC), and HITOS (Lê *et al.*, 2006) developed in Norway, for increasing the efficiency in architectural design checking. However, most of the design checking systems are based on their national building codes and cannot be directly applied in other countries; therefore, in this study, we hope to establish a BIM-based design checking model based on Taiwan architectural design regulations.

The use of the BIM as the core to integrate the information of architectural design and legal specifications should be feasible and be able to meet the needs of design checking (Zhang *et al.*, 2013). However, the information attributes of different aspects and information integration methods should still be considered in the design and in the checking phase of the construction project (Feng and Chen, 2008) to effectively implement the BIM-based architectural design checking model. Therefore, the scope of this study is set in the architectural design checking phase, investigating and discussing data collection and information conversion in the preparation phase, information provision and data recording in the checking process, and report establishment after checking; this study also aims to expand the design checking within the BIM framework, further develop an automated architectural design checking framework suitable for Taiwan, and improve the quality and efficiency of architectural design checking in Taiwan.

2. ANALYSIS AND CLASSIFICATION OF ARCHITECTURAL DESIGN REGULATIONS

There are two development methods involved for modern automated architectural design checking systems: (1) using the Add-in method in drawing software to mount the checking program, which can immediately check building design errors during the drawing process and (2) converting the BIM to an Industry Foundation Classes (IFC) file and then checking with a separate design checking system (Eastman *et al.*, 2011). In this study, we used the latter method while referencing the method proposed by Eastman et al. The architectural design checking system was divided into four parts—regulation interpretation, BIM construction, design checking, and result report (Eastman *et al.*, 2009)—among which the regulation interpretation process is the most important. For regulation interpretation, besides defining the checking information of individual articles by analyzing building regulations, in this study, we further classify the automation level of BIM-assisted checking as well as the corresponding building scale level during checking based on building regulations. The detailed descriptions are as follows.

2.1. Automation level of BIM-assisted checking

Before converting building codes written in human language into a computer program, it is necessary to first analyze and learn the architectural design regulations, set out critical determination information in architectural design regulations that can be used as determination conditions, and further analyze whether the critical determination information can be obtained using BIMs. Hence, based on the sources of critical information, the automation of regulations was divided into six levels:

(1) Direct model information: In the IFC files exported by the BIM, the required critical information is directly retrieved, and checks required by the regulations are performed, such as length, area, volume, and type of material.

(2) Indirect model information: Critical information cannot be retrieved directly from the BIM but can be obtained through program operations and then used for checks required in the regulations, for example, the total floor area and the lighting area.

(3) Expanded model information: Under the existing IFC standards, critical information cannot be provided by the BIM; it requires an expansion of its property fields in the BIM, and the user will need to enter the information during BIM construction to meet the requirements of the regulations, for example, building type, spatial attributes, glass transmittance coefficient, and usage ratio of recycled materials.

(4) External reference information: This refers to the need to use information outside of the BIM before checking on the regulations, for example, Google Earth terrain data, architectural design rules, and sunlight simulation results.

(5) Manual input: Critical information cannot be obtained by the BIM or external reference but needs to be entered manually outside of the BIM before the checks required by the regulations can be performed, for example, information on surrounding roads and chimneys on buildings.

(6) Manual determination: The regulations must be determined via specific agencies or professionals, for example, whether building designs go against customs or affect the safety of traffic lanes.

2.2 Building scale level corresponding to regulations

In addition to the classification of the automation level on the basis of building codes, in this study, we further classified building objects corresponding to the contents of the regulations in design checking to construct a consistent design content checking order, and the building scale is divided into five levels:

(1) Land level: The regulations are related to the land attributes of the building, such as land use types, residential land, and permanent open space.

(2) Building level: The regulations are related to the category of building use, for example, hospitals and schools.

(3) Floor level: The regulations are related to the floors of the building, such as floor area, floor height, and number of floors.

(4) Space level: The regulations are related to the type of space in the building, for example, bedroom, toilet and living room.

(5) Object level: The regulations are related to building components, for example, columns, beams, walls, and panels.

The architectural design checking system established in this study will conduct design content checking according to the above-defined levels in the order of land, buildings, floors, space, objects, and other related laws and regulations.

3. DATA COLLECTION AND ANALYSIS OF BIM

To establish the BIM-based architectural design checking model, in this study, we used an information conversion mechanism to convert the BIM data into the information required for design checking. The building project hierarchy (BPH) framework (Hegazy *et al*., 2001) and BIM architecture (NBIMS, 2008) were referred to in this study, and the hierarchy of the BIM was divided sequentially into Project, Site, Building, Floor, Zone, Space, and Element. Projects, Site, Building, and Floor were defined as Logical Objects according to the characteristics of the graphics object; Space and Zone were defined as Spatial Objects; columns, beams, walls, panels, doors, windows, and other building components were defined as Physical CAD Objects. They are described separately below:

(1) For Logical Objects, Project is the collection of Sites. The basic information of a project includes construction personnel, work period, and total cost; Site is the collection of Buildings and is used for describing the state of the environment, traffic routes, and the other information of the construction site; Building is the collection of Floors; and Floor is the collection of Spatial Objects. Therefore, Logical Objects in a CAD system are not the actual graphic objects but a collection of Spatial Objects and Physical Objects.

(2) For Spatial Objects, Space is confined by the surrounding components such as columns, beams, walls, and panels, forming 3D graphics objects with convex and concave surfaces and are actual existing graphic objects in the drawing software. If the space is large for a single floor, Zone-level objects can be used for constructing the group relations of Spatial Objects.

(3) Physical Object is the smallest unit of the BIM and used for representing various types of building objects. The objects of this study were classified into structural systems, building systems, mechanical and electrical systems, etc., based on the characteristics of the engineering systems. For example, the structural system contains the foundation, columns, beams, walls, slabs, and other elements; the building system includes doors, windows, ceilings, railings, and other components; the mechanical and electrical system includes lifting equipment, power generation equipment, pipelines, lighting, water supply, and other components.

After the completion of a connection analysis between checking rules and building-level attributes, Smart BIM Object can be used for describing the related contents of architectural design rules, that is, it can have a complete display of the building properties of the related graphic objects (Figure 1).

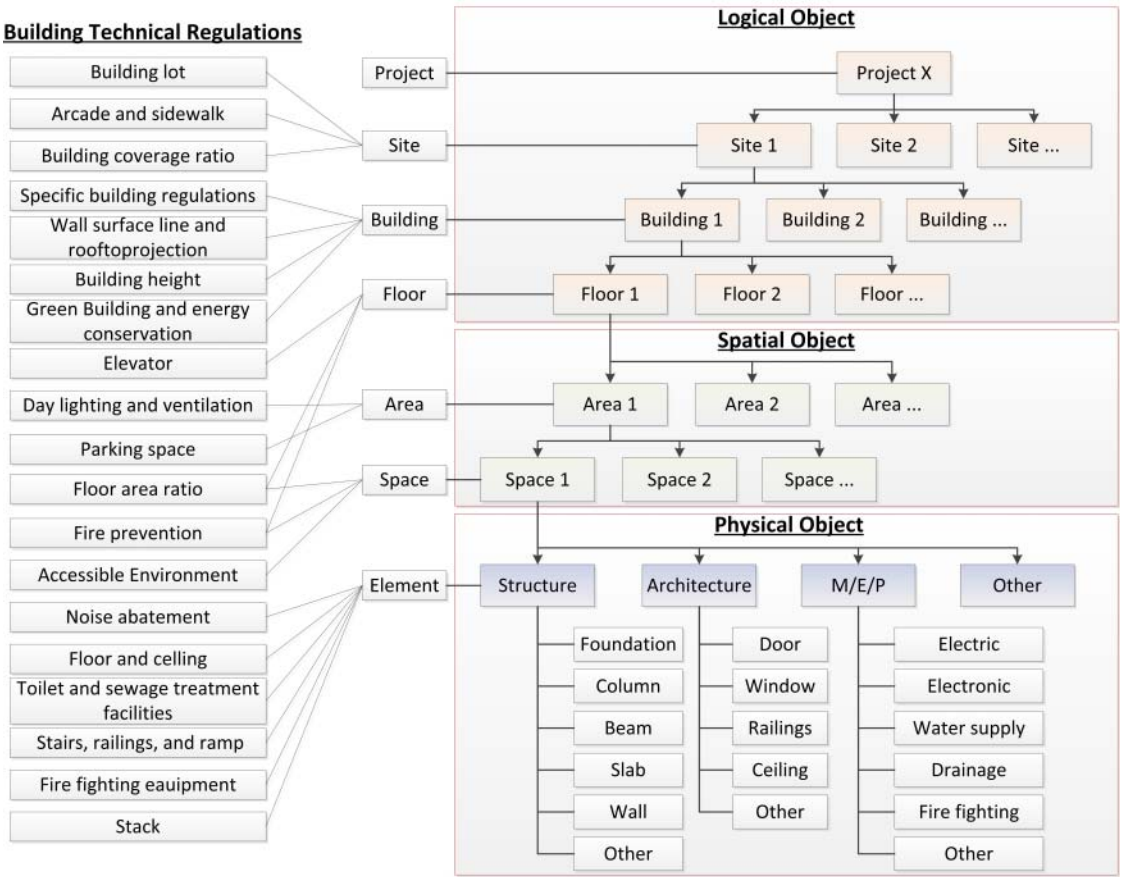

Figure 1: The connection analysis between checking rules and building-level attributes.

4. SYSTEM DEVELOPMENT AND APPLICATION

This section describes a case study and the operation of the checking system. The BIM of a project established by Autodesk Revit Architecture 2012 is shown in Figure 2. The model will be exported as an IFC file for the subsequent checking of the design content. As mentioned earlier, critical information required for architectural design checking can be directly retrieved from the BIM or obtained through program operations. Further, regulations checking could be conducted through BIM graphics object properties extension or manual information supplementing with computer software aids. In this study, the checking system was initially developed with three categories of critical information, including direct model information, indirect model information, and extended model information, as well as BIM-related regulations.

Figure 2: The BIM model of the case study.

In the development of the system, Visual C# was used for the checking program. The basic operation procedure for the system includes four steps: Open the IFC file, capture critical information, check the design content, and output results. Taking the checking of article 33 of Building Technical Regulations as an example, the main checking contents of the article was the compliance of the building stairs design with the regulations, for example, the width of the stairs and platforms, stair rise, and tread depth; the corresponding IFC information was IfcStairFlight and IfcSlab (Figure 3). After the identification of critical checking information and sources of information, the IFC file was imported into the checking system for building design checking, and the results are shown in Figure 4 below. In Figure 4, it can be seen that the building type is H2, and the contents of the regulations are displayed at the right on the screen to allow users to immediately view the inconsistency of the BIM with the regulations in the checking process. As inferred from the results of the checking, the design content has met the specifications of article 33 in the regulations, that is, the stairs were appropriately designed.

If an error occurred in the BIM design, the system would automatically mark objects with errors (Figure 5). For example, the stair rise of #7108 is 24 cm, which is higher than the limit of 20 cm in the regulation; the checking system lists this design error, and the user can search for the object using the ObjectID in the drawing software and directly locate the object with design errors (Figure 6), which improves error correction.

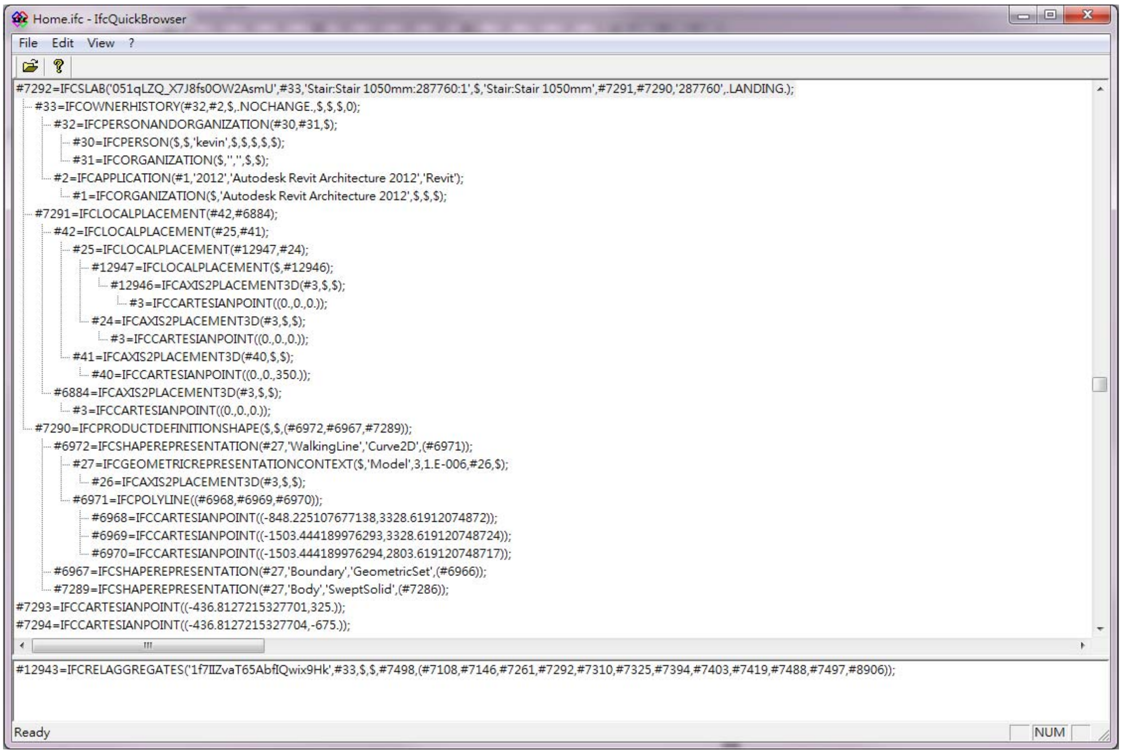

Figure 3: The IFC file of the case study

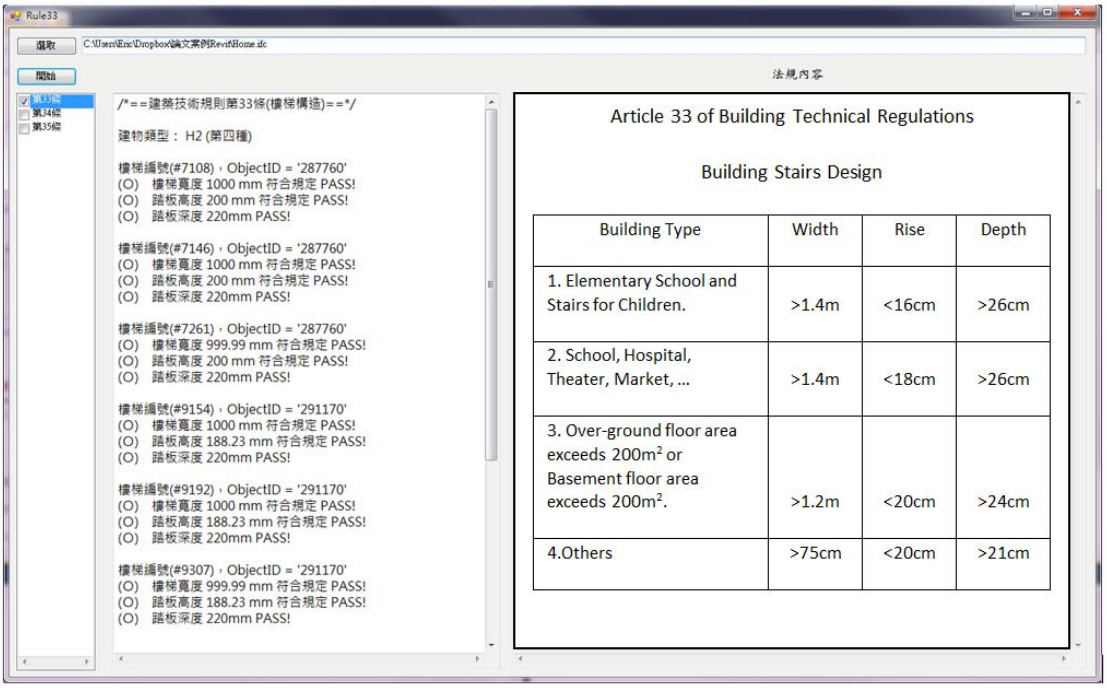

Figure 4: The results of the building design checking.

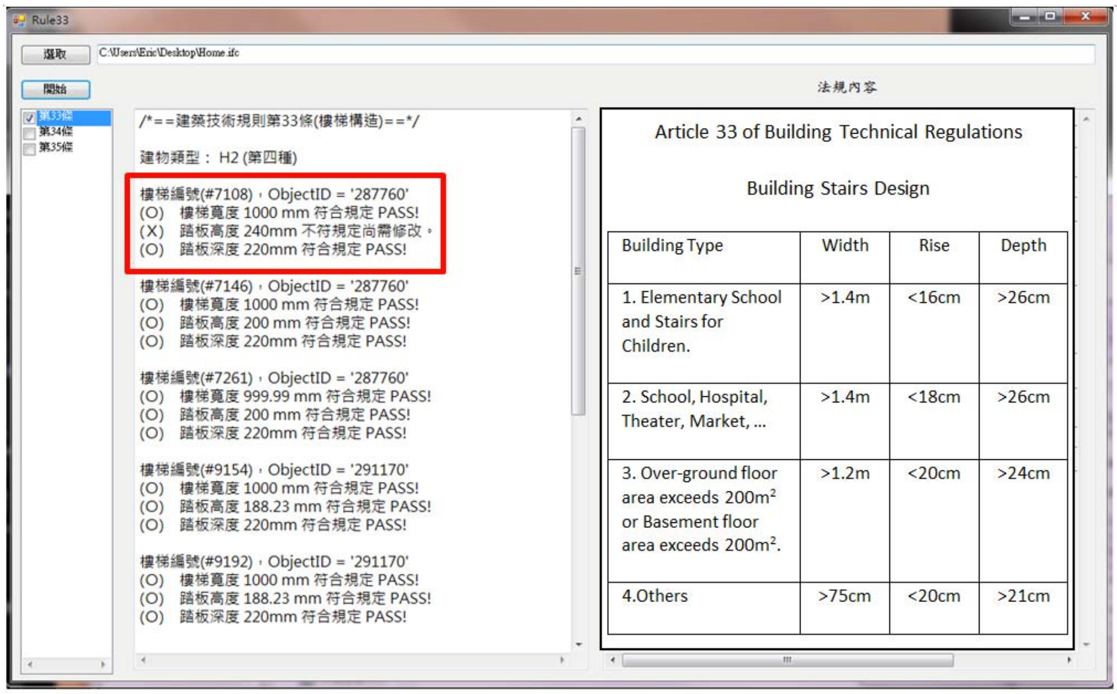

Figure 5: The design error marked by the system.

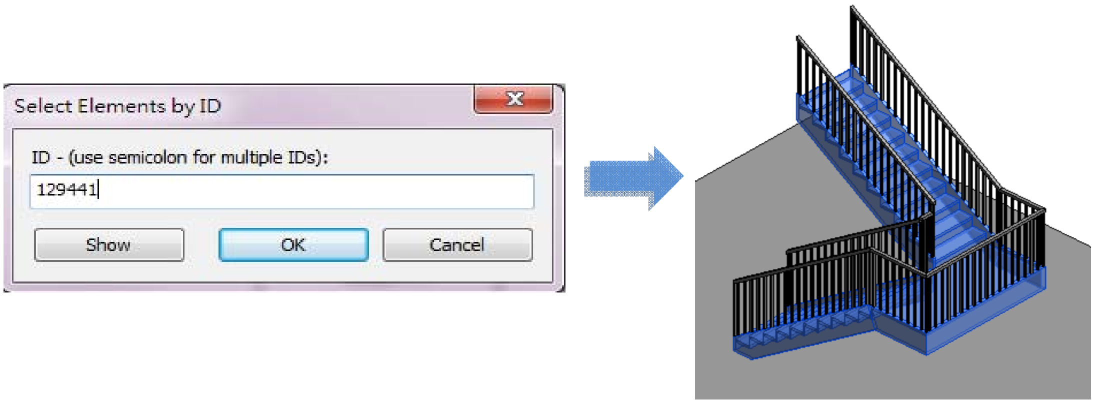

Figure 6: Search the design error object by the ObjectID in the drawing software.

5. CONCLUSIONS

BIM has been commonly applied in various fields within the construction industry. With the development of software, making good use of the characteristics of the BIM in complicated design content checking has become the main trend in all countries. In this study, based on the architectural design regulations in Taiwan, through regulations interpretation, information checking and processes compilation, BIM construction, and system development, a preliminary architecture of an automatic checking system was established in line with the regulations in Taiwan. In the verification process using a case study, it was found that the speed of checking could indeed be accelerated with the aid of the BIM and the checking system, while improving the efficiency and accuracy of checking, which were considerably helpful in enhancing the quality of the overall design. However, architectural designs involve extensive and complex aspects, and design checking aid models for structural design, mechanical and electrical design, fire design, etc., will continue to be built to make the automated checking system of the architectural design more complete.

ACKNOWLEDGEMENT

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AN IMPROVED GENETIC ALGORITHM FOR RESOURCE LEVELING OF LOB SCHEDULES

Atilla Damci
Istanbul Technical University, Istanbul, Turkey, damcia@itu.edu.tr

David Arditi
Illinois Institute of Technology, Chicago, Illinois, USA, arditi@iit.edu

Gul Polat
Istanbul Technical University, Istanbul, Turkey, gul.polat@itu.edu.tr

Befrin Neval Bingol
Istanbul Technical University, Istanbul, Turkey, bbingol@itu.edu.tr

Abstract

The resource leveling problem—which involves minimizing fluctuations, peaks and valleys in resource utilization without changing the completion time of a construction project—in schedules established by using the line-of-balance (LOB) method has been studied by only a few researchers. The purpose of this study is to extend the existing resource leveling approach for schedules that are established by using LOB. The previous resource leveling procedure for LOB schedules allows only shifting non-parallel activities by decreasing the number of crews without violating the principles of "optimum crew size" and "natural rhythm" in order to maintain optimum productivity. Parallel activities and an increase in the number of crews were not considered in the previous approach. This study proposes an improved genetic algorithm-based resource leveling model which allows leveling resources of parallel and non-parallel activities by not only decreasing but also increasing the number of crews without violating the principles of "natural rhythm" and "optimum crew size". The improved approach is demonstrated through a variation of the example project that was used to illustrate the use of the previous approach. It was observed that the proposed model provides a smoother resource utilization histogram after leveling while maintaining optimum productivity.

Keywords: genetic algorithms, line-of-balance, resource leveling, scheduling.

1. INTRODUCTION

The need for an uninterrupted utilization of resources in construction projects that exhibit repetitive characteristics stimulated the interest of researchers in developing alternative scheduling methods that are known under the generic term "linear scheduling methods". All of these "linear scheduling methods" aim to establish a schedule that utilizes resources in a manner that prevents interruptions in utilization of resources. The basic concepts used in all of these "linear scheduling methods" can essentially be traced back to the line-of-balance (LOB) methodology. LOB is described by Philip Lumsden (1968) in his seminal work. The methods developed subsequent to Lumsden's (1968) work make use of the basic principles of LOB but ignore the principle of "optimum crew size" that maintains optimum productivity and the principle of "natural rhythm" that keeps the resources utilized without idle time. For example, Peer and Selinger (1973) propose a method that shortens the project duration by modifying crew sizes; this method does not consider the LOB principle of "optimum crew size". Adeli and Karim (1997), Harmelink (2001), Harmelink and Rowings (1998), Russell and Caselton (1988), Russell and Wong (1993), Vorster et al. (1992), the vertical production method of O'Brien (1975) and the time space scheduling method of Stradal and Cacha (1982) use a single line representation for an activity rather than the trapezoidal representation of LOB; while a single line representation simplifies the LOB diagram, it does so at the expense of losing valuable detail about start and finish times of activities at individual units. The linear scheduling method of Johnston (1981), the repetitive project modeling of Reda (1990), the linear scheduling model with varying production rates of Duffy et al. (2011), and the repetitive scheduling method of Harris and Ioannou (1998) allow easy modification of production rates in order to achieve scheduling goals, while the principle of "natural rhythm" is totally ignored. Thabet and Beliveau (1994) proposed the vertical logic scheduling for multistory projects which allows changing the duration of an activity in a unit, while the durations of the activity in succeeding units are constant as long as the optimum crew size is preserved in each activity. Ignoring the principles of "optimum crew size", "natural rhythm", and details about activity start and finish times at individual units diminish the value of linear scheduling in providing an uninterrupted utilization of resources.

Even though the uninterrupted utilization of resources can be achieved by "linear scheduling methods", the utilization of resources can still be improved through resource management. "Linear scheduling methods", by their very nature, can allocate resources to minimize project duration according to constraints on resources. However, "linear scheduling methods" do not perform resource leveling. In resource leveling, the goal is to minimize fluctuations, peaks and valleys in resource utilization while the project duration is kept unchanged (Doulabi et al., 2010; Gordon and Tulip, 1997; Hariga and El-Sayegh, 2010; Leu et al., 2000; Senouci and Adeli, 2001; Son and Skibniewski, 1999). Many researchers have proposed different models for resource management in schedules that are established with linear scheduling methods. For example, Perera (1983) considers hourly resource usage in determining resource requirements and allocating resources with the help of the linear programming method. Dubey (1993) alters the minimum moment algorithm—which is a resource leveling procedure for linear schedules formerly developed by Harris (1978)—by applying new rules that enable the use of multiple locations and variable resource usage for activities with an increase in computational efficiency. Suhail and Neale (1994) propose an approach that integrates the Critical Path Method (CPM) and LOB in order to level resources according to the float times calculated by basic CPM calculations. Thabet and Beliveau (1997) develop a space-constrained and resource constrained prototype knowledge-based system that integrates both space and resource constraints in scheduling of projects that exhibit repetitive characteristics. Elwany et al. (1998) use linear programming to solve the problem of allocation and leveling of resources in construction projects that exhibit repetitive characteristics by minimizing the number of changes in resource requirements. Mattila and Abraham (1998) use linear programming and an algorithm developed by Harmelink and Rowings (1998) in determining the floats of activities that can be used in shifting them in order to level the resources. Liu (1999) proposes a tabu search algorithm for minimizing the project duration under resource constraints, which is based on the algorithm developed by Harmelink and Rowings (1998). Leu and Hwang (2001) integrate resource allocation and resource sharing for an optimal schedule under resource constraints with the help of a genetic algorithm. El-Rayes and Moselhi (2001) present an automated and dynamic programming-based approach that identifies optimum crew formation and allows interruption in activities in order to optimize resource utilization. Yen (2005) improves the model developed by Liu (1999) by adding a simulated annealing search algorithm that aims to minimize the project duration and the fluctuation in resource usage. Liu and Wang (2007) propose a constraint programming-based model that considers the temporary addition of resources required to shorten the duration of specific activities in order to minimize the total project duration or total cost. Georgy (2008) integrates genetic algorithms and AutoLISP programming language under AutoCAD for the automation of resource leveling by using an algorithm developed by Harmelink and Rowings (1998) in determining the floats of activities that can be used to shift them in order to level the resources. Hsie et al. (2009) propose an optimization model that automatically selects the optimal set of production rates for activities by considering crew composition and size in different time periods. Lucko (2011) uses singularity functions and a genetic algorithm that exhausts possible permutations of shifting activities or changes in their resource rates for resource leveling. These studies have dealt with various aspects of resource management in schedules that are established by “linear scheduling methods”, however, they ignored all or some of the basic principles of LOB methodology such as “optimum crew size” and “natural rhythm” described in detail in Section 3. Even though these studies tried to utilize resources more efficiently, ignoring these principles may end up with a loss of productivity. Damci et al. (2013) propose an approach in order to fill this gap in LOB schedules by providing a genetic algorithm-based model that deals with resource leveling by decreasing the number of crews according to the principles of “optimum crew size” and “natural rhythm”. However, this model did not consider the impact of an increase in the number of crews and the effect of parallel activities. The study presented in this paper was initiated to improve the previous model proposed by Damci et al. (2013). New rules are added to the model in order to include parallel activities to the model. The method presented in this paper is illustrated by an example drawn from the construction industry that exhibits repetitive characteristics.

2. OBJECTIVES OF THE STUDY

The objectives of this study include: (1) defining new rules to allow an increase in the number of crews and to include parallel activities in the resource leveling procedure, (2) validating the new rules through an example drawn from the construction industry that exhibit repetitive characteristics. In order to achieve these objectives, the model proposed by Damci et al. (2013) was modified by adding new rules. These new rules define the parallel activities that are candidates for resource leveling and how resource leveling would be performed for parallel activities while implementing the principles of "optimum crew size" and "natural rhythm". The model was demonstrated with the illustrative pipeline project previously presented by Damci et al. (2013) with additional parallel activities. An LOB schedule for the pipeline project was set up by calculating the start/finish times of activities and the total project duration through the basic LOB procedures. The resource utilization histogram was plotted for the LOB schedule. The activities that are eligible for resource leveling were specified before running the genetic algorithm-based model. Finally, the resource utilization histogram after resource leveling was plotted in order to compare it with the one plotted before leveling.

3. METHODS

This study employs LOB methodology for scheduling and a genetic algorithm for solving the resource leveling problem in projects that exhibit repetitive characteristics.

3.1. Lob

The initiation of the efforts for developing the LOB method is not quite clear. The U.S. Navy and The Goodyear Company were the pioneers of these efforts in the 1940s and 1950s (Arditi et al., 2002; Johnston, 1981; Tokdemir et al., 2006). Lumsden (1968) described the principles of the LOB methodology in his seminal work which made significant contributions to its development. An LOB diagram is drawn in a system of coordinates where the x-axis shows time while the y-axis shows the number of units to be produced. First of all, the duration of the production of a unit is computed by dividing its required worker-hours by the optimum crew size and daily working hours. Afterwards, the start and finish times of an activity at each unit is computed through the relationship between the number of units produced and time, which is similar to the equation of a line. Every activity is represented by two oblique and parallel lines that constitute a trapezoidal shape. In this study, the slope of these two oblique and parallel lines is called the start-to-start (or finish-to-finish) productivity rate. The left and right edges in the trapezoidal shapes represent the start and finish times of the activity at that particular unit (Arditi and Albulak, 1986; Arditi et al., 2002; Lumsden, 1968). This is the original representation in Lumsden's (1968) publication. Some of the variations mentioned earlier do use a single line rather than our (and Lumsden's) trapezoidal representation; while they simplify the LOB diagram, they do so at the expense of losing valuable detail about start and finish times of activities at individual units. We prefer using the trapezoidal shapes of the original LOB method because we can explain the principles of "optimum crew size" and "natural rhythm" much more easily and much more clearly. The principle of "optimum crew size" assumes that the highest productivity can be achieved as long as an activity is performed in a unit of production by a crew of optimum size. Any crew that is composed of fewer or more workers is bound to result in lower productivity. The production rate of an activity can vary depending on the number of crews that are used. In other words, because of the "natural rhythm" principle, an activity can be performed with a crew of optimum size. If the project manager decides to use one crew of optimum size in an activity, the production rate of this activity will be uniform all through the project. However, if the project manager wants to increase the production rate, then he/she will have to double (or triple, or quadruple, etc.) the number of crews, hence doubling (or tripling, or quadrupling, etc.) the production rate. In no circumstances should the project manager increase or decrease the crew size, as an increase or decrease in the crew size will accelerate or slow down the production rate but will sacrifice productivity, hence causing an increase in costs. For a thorough discussion of the LOB method, optimum crew size, and natural rhythm, readers are directed to Lumsden (1968), Arditi and Albulak (1986), and Arditi et al. (2002).

3.2. Genetic algorithms

The need for locating the global optimum or near-optimum solution for civil engineering problems has led researchers to use genetic algorithms that simulate the natural selection process. The following steps are required for developing a genetic algorithm in order to solve a particular problem. The first step involves representing the variables of the problem through a chromosome that consists of a series of genes that are considered to be the value of the variable, choosing the size of the chromosome population, specifying the rates for the crossover and mutation operators for reproduction, and defining the fitness function that evaluates the performance of the chromosomes as a solution for the problem (Goldberg and Kuo, 1987; Hegazy, 1999). In the second step, a genetic algorithm randomly generates an initial population and calculates the fitness values of each chromosome in the population. In the third step, a pair of chromosomes (parent chromosomes) are randomly selected for producing a new chromosome (offspring) through one of the methods that are available (e.g., roulette wheel selection, tournament selection). The chromosomes that have high fitness values are likely to be selected due to having a higher probability for producing an offspring that has a higher fitness value than other chromosomes in the population. The fourth step involves the reproduction of new chromosomes through crossover and mutation. Two selected parent chromosomes exchange their corresponding parts with each other in order to produce a pair of new chromosomes through crossover (e.g., one-point crossover, two-point crossover, uniform crossover). The decision of which technique should be used for selection or crossover depends on the nature of the problem or the preference of the user. Stagnation in the reproduction process can be broken by the mutation operator that allows producing a new chromosome through changing the genes of a parent chromosome. In the fifth step, the produced chromosomes are evaluated through their fitness values. The new chromosomes that have higher fitness values are replaced with the ones that have lower fitness values. Finally, the process repeats itself starting from the second step until a chromosome that represents the optimum or near-optimum solution is generated (Hegazy, 1999; Leu et al., 2000; Negnevitsky, 2002; Senouci and Eldin, 2004). A metaheuristic method is preferred (e.g., genetic algorithm) to an analytical method (e.g., linear programming) or a heuristic method (e.g., using rules of thumb) due to the following reasons; (1) an optimum solution for a large-scale problem may not be found by analytical methods, (2) a model developed by a heuristic method has a problem-dependent nature so that it cannot provide solutions for different cases. These shortcomings may be overcome by metaheuristics (e.g., genetic algorithms). However, even though a genetic algorithm has a problem-independent nature in solving large-scale problems, it may fail in providing the optimum solution for the problem (Hegazy and Kassab 2003, Chen and Weng 2009, Hariga and El-Sayegh 2010).

4. IMPROVED RESOURCE LEVELING PROCEDURE FOR THE LOB METHOD

The principles for leveling resources on non-parallel activities in an LOB schedule were described by Damci et al. (2013). The modified resource leveling procedure proposed in this study adopts the same principles used for non-parallel activities, but adds new principles for non-parallel and parallel activities. As in the traditional principles for leveling resources on non-parallel activities, the modified resource leveling procedure is based on the principles of “optimum crew size” and “natural rhythm”. These principles allow shifting the start times of a parallel activity forwards or backwards at different units by changing the number of crews used for the activity. The following principles are established to shift the start times of parallel and non-parallel activities:

(1) Activities B and C are parallel activities in Figure 1a.They have a finish to start relationship with the preceding (Activity A) and succeeding (Activity D) activities and a logical constraint with the preceding activity (Activity A) in the first unit and with the succeeding activity (Activity D) in the last unit. They are both predecessors of Activity D. The start time of Activity D is determined by the finish time of Activities B or C in the last unit. In Figure 1a, the slope of Activity C is less than the slope of Activity B; therefore the start time of Activity D is determined by the finish time of Activity C in the last unit. Activity C is not eligible for resource leveling, because any change in its start and finish times may change the completion time of the project or violate the relationships or logical constraints. Activity B is the candidate activity for the proposed resource leveling procedure, because its start and finish times can be changed without changing the completion time of the project or violating the precedence relationships and logical constraints. The slope of Activity B can be greater or equal to but should not be less than the slope Activity C started out with.

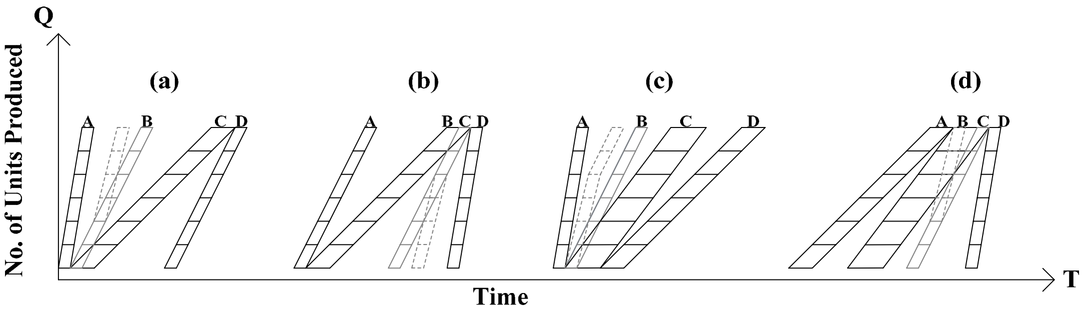

Figure 1: Examples of LOB diagrams for new principles of resource leveling

(2) The traditional approach for resource leveling in LOB allows only a decrease in the number of crews for shifting the start times of activities (Damci et al., 2013). The modified resource leveling approach allows not only a decrease but also an increase in the number of crews for shifting the start times of both parallel and non-parallel activities. If only one crew is assigned to an activity, then the number of crews on that activity can only be increased but it should not exceed the number of available crews that was specified by the construction manager at the beginning of the project. The earliest change in the number of crews can be accommodated only after the first crew moves to its next destination and the precedence relationships and logical constraints should not be violated. In Figure 1, the activities represented by dashed lines show the start and finish times of activities after increasing the number of crews according to the new principles for resource leveling. This increase can apply to all units or to only some units. For example, Activity B in Figure 1a is eligible for resource leveling. Only one crew was assigned to Activity B in the initial schedule and the number of available crews is specified as two by the construction manager. Activity B may use 1 crew in the first three units and 2 crews in the last four units in order to achieve a smoother distribution of resources. If more than one crew is assigned to an activity in the initial LOB schedule, then the number of crews can be decreased according to the principles that are used in the traditional approach or can be further increased according to the principles that are defined in this study.

The new principles for resource leveling in LOB are included in the genetic algorithm-based resource leveling model proposed by Damci et al. (2013). In the new model, the module that performs basic calculations to set up an LOB schedule works exactly in the same way as the traditional model. It calculates the start and the finish times of the activities according to the information provided by the scheduler (e.g., production rates, number of crews). It automatically plots the LOB schedule and its resource histogram. The module that deals with resource leveling through a genetic algorithm is modified according to the principles that are proposed for parallel and non-parallel activities. The chromosome representation, the objective function for resource leveling (minimization of the sum of the absolute deviations between daily resource requirements and the average resource requirement) and the required values of the genetic algorithm operators (e.g., population size, crossover rate) were kept the same as in the previous model. The constraints that set the principles for resource leveling were modified according to the new principles. Modified resource leveling allows not only decreasing but also increasing the number of crews used in activities in order to level the resources that are assigned to them. Modified resource leveling tries the possible combinations of crew assignments in different units by accommodating the earliest change in the number of crews only after the first crew moves to its next destination and without affecting the completion time of the project, the duration of an activity in any unit, the precedence relationships, and the logical constraints. The genetic algorithm-based model discards the solutions that do not meet the constraints that have been specified according to the principles mentioned in this section.

5. EXAMPLE AND RESULTS

The modified resource leveling procedure is illustrated through a variation of an example pipeline project previously presented by Damci et al. (2013). In the new example, two parallel activities (Transport of Aggregates - Activity H and Maintenance of Equipment - Activity J) were added in addition to seven consecutive activities that repeat themselves kilometer after kilometer throughout the project. Activity H is parallel to Activities A and B; Activity J is parallel to Activity D. Information about these activities is presented in Table 1 and is used in establishing an LOB schedule.

Activity Name	Required Worker Hours to Finish Unit	Number of Workers in Optimum Crew	Daily Working Hours	Duration (days)	Number of Crews	Maximum Number of Crews	Start-to-Start Productivity Rate (km/day)
(A) Locating and clearing	24	3	8	1	2	2	1
(B) Excavating	32	8	8	0.5	2	2	4
(C) Laying aggregate	40	10	8	0.5	3	3	6
(D) Laying pipes	84	7	8	1.5	2	2	1.33
(E) Testing	64	4	8	2	4	4	2
(F) Backfilling	144	6	8	3	5	5	1.67
(G) Compacting	160	10	8	2	2	2	1
(H) Transport of Aggregates	16	4	8	0.5	1	2	2
(J) Maintenance of Equipment	12	3	8	0.5	1	2	2

Table 1: Information about activities

This information can be obtained through the personnel of a company that has experience in similar projects. Even though a pipeline project can be completed by several resources assigned on the activities, only workers employed by the contractor were considered in this study for demonstration purposes. The pipeline project is 26 km in length and should be completed in 55 days. Only one crew is assigned to each activity in order to establish the first schedule which exceeded the contract duration of 55 days. The principles proposed by Tokdemir et al. (2006) were used in accelerating the schedule, which resulted in a project duration of 51 days (Figure 2). The initial schedule allows the scheduler to determine the eligible activities for resource leveling. Excavating (Activity B), backfilling (Activity F), transport of aggregates (Activity H) and maintenance of equipment (Activity J) are the eligible activities for an improved resource leveling procedure according to the principles presented earlier.

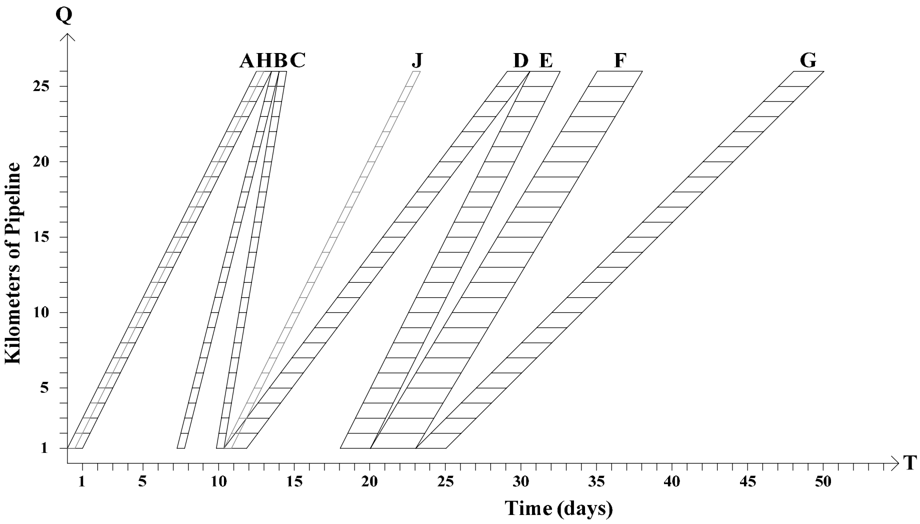

Figure 2: The LOB schedule before resource leveling

The total workforce used in the project can be calculated with the information of the number of workers in an optimum crew, the duration of the activity and the number of kilometers of the pipeline project in each and every activity. First, the total number of workers used in an activity is calculated by multiplying the number of workers in an optimum crew by the duration of the activity and by the number of kilometers of pipeline in the project. Afterwards, the total workforce used in the project is expressed as the sum of the number of workers in each and every activity. The total workforce used in the example pipeline project is 1,872 worker-days as seen in Figure 3. The average number of workers per day is calculated by dividing this number by duration of the project (51 days). The outcome is 36.71 workers/day. This result is rounded up to 37 due to the nature of the resource (i.e., worker) that is used in this study.

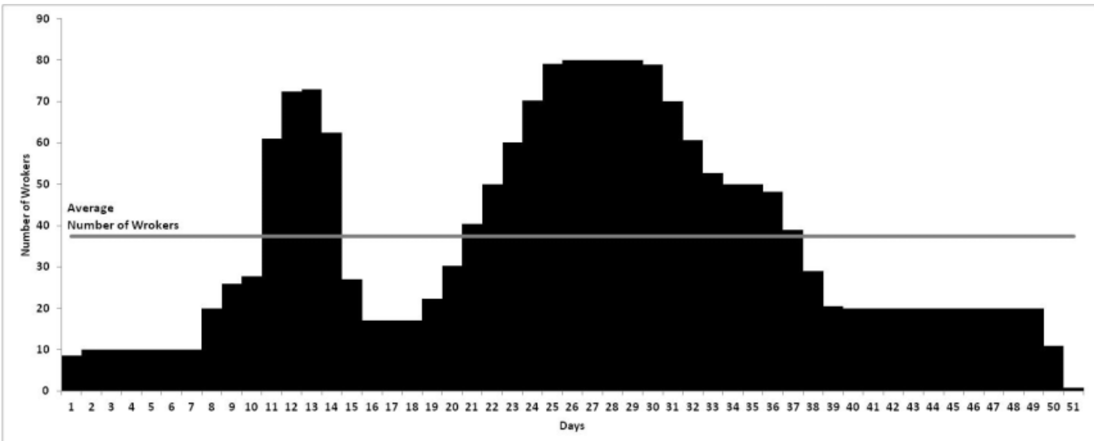

Figure 3: Resource histogram before resource leveling

Once all the required information is input to the system, the genetic algorithm-based resource leveling model was run. It was stopped after 50,000 trials because the model stopped generating a better solution. It provided the LOB schedule and the resource histogram shown in Figures 4 and 5. The completion time of the construction project, the logical constraints and the interdependencies were not violated during resource leveling. As seen in Figure 4, Activity H used 2 crews (maximum number of crews for Activity H) in the first 13 units and 1 crew in the following units. On the contrary, Activity J used 1 crew in the first 11 units and 2 crews (maximum number of crews for Activity J) in the following units. Activity F started with 5 crews, continued with 3 crews and completed the project with 2 crews. Activity B started with 1 crew and completed the project with 2 crews.

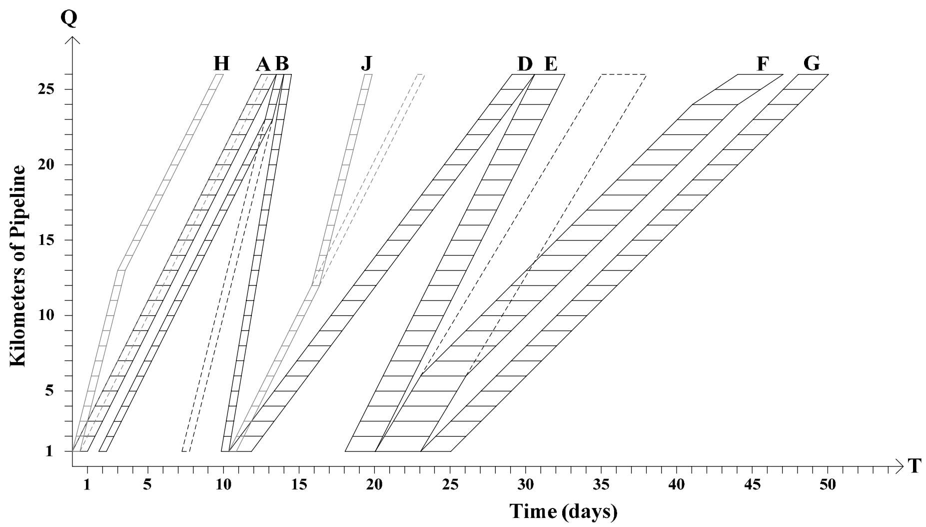

Figure 4: The LOB schedule after resource leveling

It is observed in Figure 5 that after resource leveling, the sum of the absolute deviations between daily resource usage and average resource usage is reduced from 1,663 to 1,305, which corresponds to an improvement of 22%. As a result, it can be concluded that the modified approach does indeed provide a smoother resource histogram while maintaining optimum productivity by keeping the principles of "optimum crew size" and "natural rhythm" while using parallel activities. In practice, parallel activities are inevitable in real life construction projects. If the parallel activities had been ignored for resource leveling in the example presented in this study, the improvement would have been only 19% which corresponds to a loss of 3%. In a large-scale construction project, 3% loss in improvement of resource utilization may have a negative impact on the cash flow.

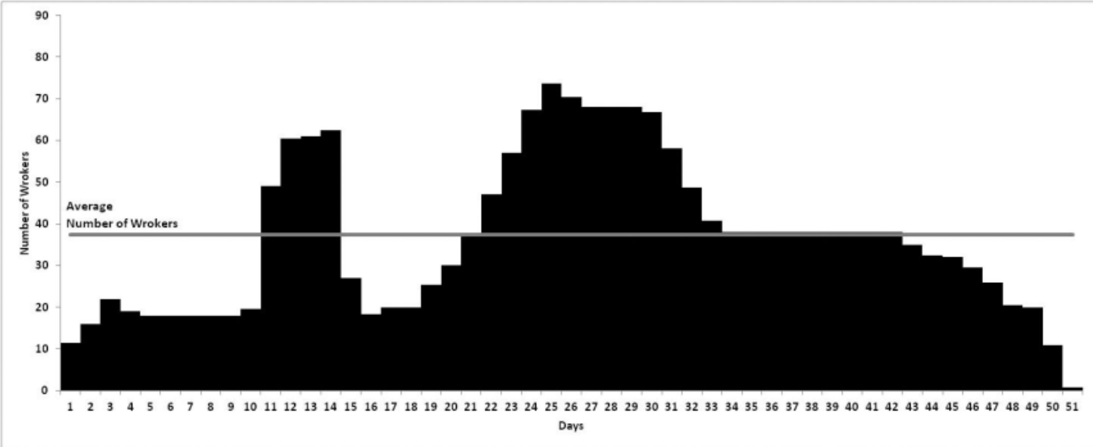

Figure 5: Resource histogram after resource leveling

6. CONCLUSIONS

In this paper, new principles are proposed to extend the existing resource leveling approach for schedules that are established by LOB. The traditional resource leveling procedure for LOB schedules allows only shifting non-parallel activities and by decreasing the number of crews. The major contribution of the improved resource leveling approach is that it allows shifting both parallel and non-parallel activities, and not only decreasing but also increasing the number of crews without violating the principles of “optimum crew size” and “natural rhythm”, hence maintaining optimum productivity. The improved resource leveling approach was applied to an example project that exhibits repetitive characteristics. The results showed that the improved resource leveling procedure provides a smoother resource utilization. Future work should be undertaken to explore multi-resource leveling and to consider different objective functions for resource leveling.

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DEVELOPING A SAFETY TRAINING SYSTEM FOR CHINESE METRO CONSTRUCTION WORKERS

Lieyun Ding
Huazhong University of Science and Technology, Wuhan, China, dly@mail.neu.edu.cn

Sheng Xu
Huazhong University of Science and Technology, Wuhan, China, sheng_xu@hust.edu.cn

Hanbin Luo
Huazhong University of Science and Technology, Wuhan, China, lhblhb1963@vip.sina.com

Shengyu Guo
Huazhong University of Science and Technology, Wuhan, China

Siqi Wang
Huazhong University of Science and Technology, Wuhan, China

Abstract

Workers' unsafe behaviour is recognised as one of the important risk sources in the construction industry. In metro construction in China, workers are usually inexperienced, poorly educated and barely trained. Therefore, they lack adequate safety knowledge and safety awareness. Unsafe behaviours are commonly detected on construction sites in China, which leads to the need to develop an effective safety training system for Chinese metro construction workers. Although the construction industry has received many benefits from information technology, in many ways, the information and communication technologies are less commonly applied to safety training for front-line workers. This research aims to develop a web-based safety training system that contains visualised training materials for the less-educated Chinese metro construction workers. This research resulted in the development of a web-based safety training program for construction workers and supervisors. This paper reports the system functions, including personal information, safety learning, safety awareness assessment, safety knowledge quiz, and results analysis, providing construction workers and supervisors web-based safety training programs. The key component of the system is the question bank, which is built upon 387 illustrative images of metro construction operation codes and 30,000 photos taken from on-site patrols. While the system supports individual workers to review their historical progress, it also supports decision making for more efficient safety management by providing historical results analysis for supervisors. Satisfactory evaluations showed that the users believed that the illustrative internet-based safety training programs were able to greatly improve safety knowledge and awareness among Chinese metro construction workers.

Key Words: front-line workers, illustrative learning materials, metro construction, web-based training system.

1. INTRODUCTION

Safety training and education is an important issue in Chinese metro construction. The scale and speed of metro construction poses higher requirements for safety management. Because of the massive amount of new construction, large groups of new workers come into the construction industry without proper skills or enough experience, and the number of new workers has increased by more than 1 million per year (State Council Research Group, 2006). Less than 7% of them attended vocational training programs. The similar problem also exists in developed countries. According to statistics, there were more than two million Hispanic workers in the construction industry in the U.S., and those Hispanic workers also had the highest injury and fatality rates (Nancy Nivison Menzel & Antonio P. Gutierrez, 2010). Human errors and unsafe behaviours contribute greatly to accidents (HSE, 2002) (J. Reason, 1990), J. W. Garrett and Jochen Teizer (2009) pointed that previous research showed human factors accounted for 90% of all accidents in complex industries with high risks, and inexperienced workers are more likely to perform unsafe behaviour and cause accidents.

Many researchers have dedicated to the improvement of construction safety performance. A peer-led participatory training program was implemented on 300 New Jersey Latino construction workers, in which trained volunteer workers, instead of teachers and outside trainers, gave construction health and safety training and guidance to their peers for at least 6 hours (Q. Williams, Jr. et al., 2010). This training program was believed to be tailored to the needs of front-line workers and may have a positive impact. P. Kines et al. (2010) proposed an innovative safety intervention program by encouraging verbal safety communication between leaders and workers with pre-post control test. Feedback, observations, and safety climate questionnaires results revealed significantly lasting improvement on the level of safety knowledge and behaviours (P. Kines et al., 2010).

Among these interventions, training is the most traditional and popular method, and it provides essential knowledge about safety risks and proper working instructions. In particular, usually due to their language and literacy level, immigrant workers have bigger problems in lacking proper knowledge about occupational health risks and safe behaviours. In the U.S., a large proportion of them do not speak English, so the regular safety training programs are not applicable to them. Many efforts have been dedicated to localise Hispanic training materials, for example, a computer-based safety solution was developed specifically for Hispanic construction workers using information and communication technologies. It was reported that the workers reacted positively to the materials and gained knowledge through the training program (Carlos Evia, 2011).

In Chinese metro construction, only 61.4% of construction workers have received occupational training and there are several problems with workers' onsite safety training. Firstly, most training programs rely on classroom teaching, which presents the information in such a way that workers are easily bored and find it difficult to memorize. Secondly, metro construction is complicated and hazardous. There are many codes and instructions for workers to follow, which are neither well organised nor compiled into one reference and are, therefore difficult for workers to remember and carry out. Thirdly, many construction workers are under educated and highly mobile; according to (Fenglan Luo, 2008), half of these workers did not stay at one site for more than 6 months. Due to the massive scale of new construction in densely populated areas, research must identify statistically reliable methods to improve front-line safety knowledge and attitude.

Therefore, this research aims to develop an innovative safety training system that (1) includes all occupational hazards and behavioural instructions that the workers must know, and organises them by trade and construction progress systematically; (2) is easily understandable and welcomed by under-educated metro construction workers, for them to memorise and apply the safety knowledge in their daily work; and (3) provides standardised, structured and systematic training programs for construction workers, so that they are able to receive monitored and targeted repetitive training sessions to improve their safety performance. To achieve these goals, two important techniques are used. The first is information and communication technology and the second is visual language and scheme theory. They are most vulnerable to construction accidents, yet they are also one of the greatest sources of risk. Therefore, it is important to improve workers’ safety knowledge and behaviour with information technology. The next section introduces the development of questions bank, which is the core module in this safety training system, followed by an introduction of system functions. This research is still at its early stage, so behaviour data from the observations and comparisons is not available yet, but this paper describes the results from user satisfaction survey. Finally, discussions and conclusions are presented.

2. DEVELOPMENT OF THE QUESTIONS BANK

The safety training system is built on a database of training materials, which is called the question bank in this paper. The questions bank should: (1) contain enough questions for every trade; (2) be easily understandable. Extra care in developing training materials is needed for Chinese metro construction workers compared to their supervisors, or workers in manufacturing, or construction workers in developed countries. Workers generally have less education than the average population, so regulations, codes and guidelines written in literal language are difficult for them to understand and memorise, especially when the guidelines are complicated.

A possible alternative of literal language is the visual language. Visual language is the close integration of visual and word elements. It is believed that humans can only express concepts in three ways, sounds, body movements and drawings. This corresponds to the three learning styles of humans, auditory, telekinesthetic and visual. The visual style is the most common learning style in human beings. Visual language has many formats, such as engineering diagraming, visual metaphors, animation technologies, cartoon conventions, qualitative graphs and charts, film narrative conventions, illustrative photography, and mechanical drawings (Robert E. Horn, 2001). It is well recognised that visual language can enhance communication and knowledge transfer (Robert E. Horn, 2001; Grazyna Slusarczyk, 2012). In this way, the visualised materials provide attractive, understandable, direct and interesting training to under educated Chinese metro construction workers, so that the workers are motivated to join safety trainings.

As a result, the materials, described below, were translated into a visual language. The process can be divided into three stages, as shown in Fig.1: in Stage 1, material sources were identified, and items involving behaviour safety were acquired, categorised and structured; in Stage 2, these materials were translated into the visual language; and finally, in Stage 3, the visualised materials were transformed into questions and stored in the questions bank with certain rules.

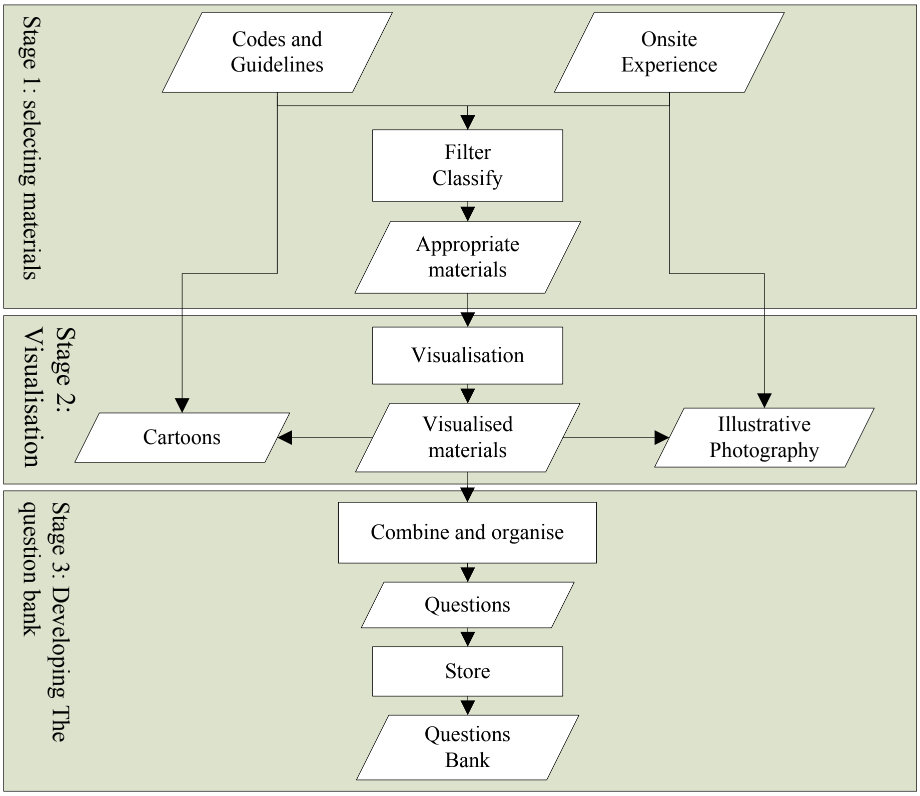

Fig.1 Stages of developing the question bank

2.1. Selecting materials

There were two sources of materials: safety regulations, standards and codes, and on-site experience. For metro construction in China, there are about 20 regulations, standards and codes that need to be followed. In particular, special attention must be paid to the following three sets of codes: (1) *Codes for Construction and Installation Workers' Safety Operation*, including 16 chapters and 300 clauses on 12 trades, 3 template construction methods and 1 chapter for general rules; (2) *Standard for Construction Safety Assessment of Metro Engineering*, including 8 chapters and 197 clauses. (3) The *Code for Beijing Construction*

Workers' Safety Operation, which is applicable in Beijing and includes 36 chapters and 935 clauses, was also referred to in identifying safety operation codes. The *Codes for Construction and Installation Workers' Safety Operation* was scanned first because it is applicable to the entire country. The *Code for Beijing Construction Workers' Safety Operation* explains the behaviours in detail, so it was scanned later as a complement.

Another source of material is on-site experience. The Institute of Construction Management in Huazhong University of Science and Technology worked closely with metro construction participants in Wuhan, Shenyang, Zhengzhou and Shenzhen for over 6 years and provided consulting services on their safety management. Engineers from the Institute patrolled metro construction sites every day and took photos whenever they identified a safety problem such as, workers without helmets or lack of fences or other barriers. 18 engineers have patrolled on 33 metro construction sites in Wuhan Metro Line 2 and Line 4, and took more than 20,000 photos from those plants on more than 1000 workers.

These source materials were then categorised and organised. The first step was to classify these materials by trades. There are two layers of trade categorisation: the first one is to determine whether the clause applies to all trades, for example, "wearing helmet" is a clause that applies to all trades; the second one is to determine to which specific trade a clause applies if not to all trades, for example, rules for an excavator only apply to mechanical operators. Most clauses in the *Codes for Construction and Installation Workers' Safety Operation* and *Code for Beijing Construction Workers' Safety Operation* are already categorised by construction trades. However, there are still some clauses for which the trade was not clarified. These clauses were categorised into multiple trades or considered general clauses by experienced engineers. The clauses in the *Standard for Construction Safety Assessment of Metro Engineering* were filtered because many of them do not target front-line workers, and are categorised afterwards into general clauses or trade-specific clauses.

2.2. Visualising materials for Chinese metro construction workers

In this research two formats of visual language are used, namely cartoon conventions and illustrative photography. The risk sources in the codes were translated into illustrative cartoons that include both risky and safe behaviour. On-site experience was represented by illustrative photos taken from the patrols, which were filtered and classified.

The first step to visualise the safety codes was to identify if the clause was suitable for cartoons. Some of the clauses were difficult to present in a drawing, and the non-compulsory clauses that did not include the words like "must" or "must not" were omitted. Secondly, the risk sources in each clause were identified because the risk sources were the main focus of the cartoons and questions. For example, a clause in the Codes for Construction and Installation Workers' Safety Operation indicates "Loaders cannot be operated on slopes, and no humans can be under the bucket, irrelevant persons and obstacles should be kept away from the working zone". In this clause, there are three risk sources, slopes, human under the bucket and human or obstacles in the working zone.

The third step was to design the cartoons. A group of digital media specialists helped draw the cartoons, but they did not understand the terms and expressions in the construction industry. Therefore, researchers wrote scripts for the cartoons and communicated with the specialists weekly to correct any mistakes. Writing the scripts required elements design. For example, in the loader's case mentioned above, a series of pictures' elements were designed with comparisons of the three risk sources: loaders on a slope and loaders on a flat surface; a worker under the bucket and no workers under the bucket; a welder in the working zone and a cleared working zone. Huge effort was required and invested in communicating the professional terminology of the construction industry to the specialists. Pictures of the materials and equipment in metro construction projects were provided as references, such as loaders, bagged cement, scaffolds, welders and so on. Vague descriptions in the clauses were also clarified, for example, the clause said "inclined desktop"; the script was written as "draw a table with one leg shorter than the other three". This amount of communication was also very necessary to help the specialists create cartoons that "looked like" real scenarios on construction sites. For example, the scaffolds looked distorted at the beginning of this process. The researchers provided several photos of the real scaffolds to the specialists. The key to "real looking" scaffolds was to draw thinner lines and to place emphasis the crossover nodes. In this way, the specialists could design the cartoons with simple lines and shapes that were clear and easily understandable to Chinese metro construction workers. The development of the materials which were turned into the questions occurred over a period of six years and was very expensive.

Because on-site photos are in the form of pictures already, the task is to identify the risk sources and problematic points in the picture. For example, all risky behaviours were circled in a photo with a corresponding photo in which no such behaviours were identified. The photos are presented in pairs. Examples of visualised materials are shown as follows. More analysis needed to be done with the photos. Two researchers examined all photos and identified any unsafe behaviour in the photos with circle markings. In this way, the photos could be linked to the categorised risks in the risk list. In addition, unsafe behaviour which occurred more than 100 times in patrol photos were further highlighted as recurring unsafe behaviour. Examples of visualised materials are shown in Fig. 2.

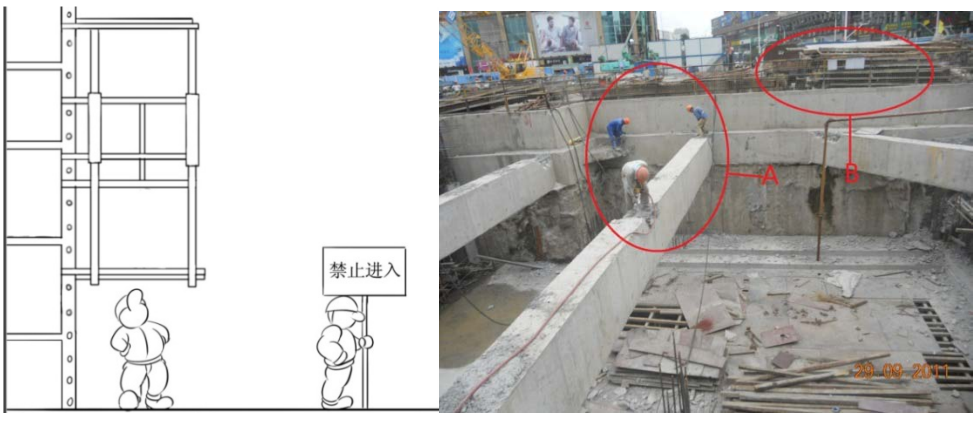

Fig.2 Examples of visualised materials

2.3. Developing the question bank

After the materials were visualised, the questions could be developed. There were three groups of questions with increasing levels of difficulty. The levels of difficulty were determined by the number of choices and risk sources. For example, in the loader case, the least difficult question is a yes-or-no question such as “Is the following picture a safe scene”; the question with average difficulty contains two risk sources and has three choices; and the most difficult question contains three risk sources and has four choices. The process from clauses to drawings and questions in the question bank is shown in Fig. 3:

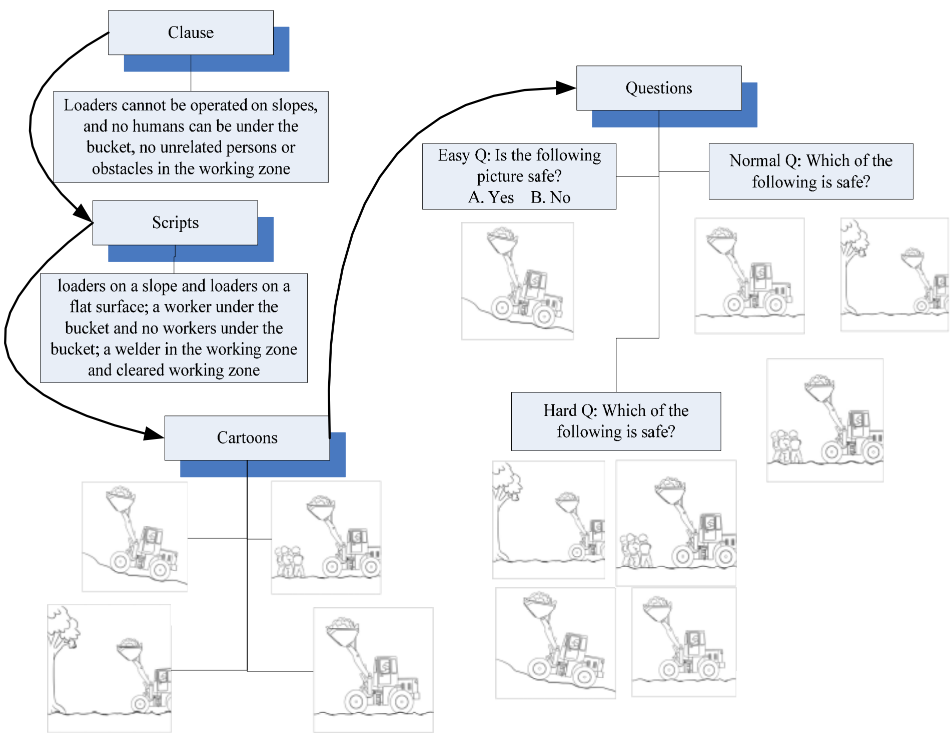

Fig.3 Developing the questions bank

3. SYSTEM FUNCTIONS

The system is made up of 6 modules, namely personal information, safety awareness assessment, safety training, results analysis, control and administration as well as 2 interfaces, the end-user interface and administrator interface.

The first four modules are presented in the end-user interface, which is the interface displayed to front-line workers. The administrator interface includes both the control module and administration module. Fig. 4 shows the end-user interface.

Fig 4 End-user interface

Personal information

This module allows workers to identify themselves and indicate essential demographic information including age, trades, construction site, length of time in the construction industry, length of time on this construction site, and previous safety training experience. The identification of a workers' trade informs the training system to generate trade-specific questions from the question bank when they take the exam. The information about how many years workers have been in the construction industry is an indicator of the assumed working experience and safety knowledge of a worker. The information about their previous training experience indicates their baseline level of safety awareness and knowledge.

Safety awareness assessment

This module assesses metro construction workers' safety attitude and safety awareness. It is based on a questionnaire, developed by the research team at HUST, which has been validated and proven reliable. The questionnaire divides the safety attitude of respondents into three levels, namely "good attitude", "average attitude" and "poor attitude". In this way, the safety awareness of construction workers can be assessed and maintained for progress watch. Furthermore, the indicator of safety attitude level helps to generate correspondent questions from the question bank. The purpose of dividing questions and workers into three levels is to cross-reference their safety awareness and knowledge so that the overall evaluation of construction workers' safety performance is more complete. This information can be used as a management tool to determine what and how much safety training needs to occur, who needs to receive what training, and which workers could be further trained as peer trainers.

Safety training

This module is the core module to conduct safety training programs for front-line construction workers. 20 questions are randomly chosen from the question bank according to workers' trade and safety awareness assessment. The process of answering questions is the training mechanism to proactively correct behaviour. Unsafe behaviour as defined in the operation codes that were of high frequency and severe consequences were chosen and illustrated. The training program relies on the idea of recognising unsafe behaviours and demonstrating safe behaviours. The answers and explanations are presented to the worker in a latent manner, which means that the respondents are required to answer the questions, and also, to then click the "check answers" button to read the correct answer and the corresponding explanations before they can proceed to the next question. An example of explanation is shown in Fig. 5.

Fig. 5 Examples of explanations to the question

Results analysis

This module supports workers to track their progress by providing their historical training results. The web-based training system is easily accessible and handy to use. Historical training results and weak points are recorded. In this way, frontline workers are able to log in the system whenever they need to, and get a clear picture of their progress. They can also log into the system if they need a refresher on a specific regulation or situation.

Control module

The system provides control panels to demonstrate the average and individual training progress within any defined group. Supervisors s are thus informed of the overall results and the best, worst and most progressed workers, and can develop corresponding incentives to reward them. In addition, the system also pinpoints the questions that many respondents fail to answer correctly, and advises extra emphasis on these areas of safety knowledge and awareness.

Administration Module

This module has two functions. The first function provides a framework to enter questions into the question bank. This framework helps to assign the attributes of trade and difficulty level to each question. Furthermore, it inserts images t into the questions, choices and explanations because the questions rely heavily on visual information.

The safety responsibilities of all participants in the project are demonstrated in the limits of authority function. Owners, project managers, consultants and supervisors have different authority to monitor groups of workers and oversee their progress in safety knowledge and awareness. Thus, they are able to gather necessary information for better decision making.

4. USER SATISFACTION SURVEY

A preliminary test of the effectiveness of this system was conducted by a satisfaction evaluation questionnaire after the first training. A total of 20 workers from one of Wuhan Metro construction sites took part in the training. They were organised by the project manager and supervisors. The researchers introduced the program and demonstrated the training system first, and then the workers took 20 minutes to answer the questions online and finished the satisfaction survey. The results were also considered as feedback to improve the system. The questionnaire covers the following aspects: demographic information, satisfaction with the contents; satisfaction with the training method; satisfaction with the time used; satisfaction with the organisation; plus the overall satisfaction. The questionnaire results were analysed with a 5-point Likert scale, and the questions are listed as follows.

	Questions (choices)	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	Average
1	**Age**（A Under 20 B 20—25 C 25-30 D 30-40 E Over 40）	0.00	8.33	33.33	58.33	0.00	3.50
2	**Frequency of past trainings**（A Often B Sometimes C Once or twice D Never E Not sure）	25.00	58.33	16.67	0.00	0.00	1.92
3	**Instructions of the system**（A Very clear, B Clear, C OK, D Not very clear, E Very unclear）	0.00	66.67	33.33	0.00	0.00	2.33
4	**Easy to use**（A Very hard, B Hard, C OK, D Easy, E Very easy）	0.00	0.00	41.67	50.00	8.33	3.67
5	**Safety awareness questions**（A not many, B acceptable, C ok D A little too much, E too much）	8.33	41.67	33.33	16.67	0.00	2.58
6	**Do you think the questions are varied?**（A always the same, B not varied, C OK, D varied, E very varied）	0.00	16.67	66.67	16.67	0.00	3.00

7	**Do you think the content fits your daily work?** （A Not at all, B No, C Just fine, D It fits, E It fits very much）	8.33	0.00	41.67	41.67	8.33	3.42
8	**Are you satisfied with the training environment and facilities?**（A Not at all, B No, C Just fine, D Like it, E Like it very much）	0.00	0.00	33.33	58.33	8.33	3.75
9	**Frequency of safety training?**（A weekly, B fortnightly, C Monthly, D Every two months, E Less than every two months）	8.33	0.00	41.67	41.67	8.33	3.42
10	**How do you like the training overall?**（A Not at all, B No, C Just fine, D Like it, E Like it very much）	0.00	8.33	50.00	41.67	0.00	3.33
11	**Do you think the training fits your expectations?**（A Yes, very much, B Yes, somewhat, C Not sure, D No, not very, E Not at all）	0.00	58.33	33.33	8.33	0.00	2.50
12	**Do you think the training is helpful to the project?**（A Yes, very much, B Yes, somewhat, C Not sure, D No, not very, E Not helpful at all）	8.33	66.67	16.67	6.33	0.00	2.25
13	**Do you think the training helps you work safely?**（A Yes, very much, B Yes, somewhat, C Not sure, D No, not very, E Not helpful at all）	16.67	75.00	8.33	0.00	0.00	1.92

Table 1 Satisfaction Questionnaire and Results

Attendees also responded to a satisfaction questionnaire on the training system. All respondents felt that the directions of the training system were “clear” or “fair”; half of the respondents felt that the system was “easy to use”, and 8.33% of them felt that it was “very easy to use”, while the rest felt that it was “fairly” easy to use. In regards to whether the training system met the requirements for daily work, 75% of all respondents believed that the system would be very helpful and another 16.67% of all respondents admitted it would be somewhat helpful, but there were 8.33% who did not believe it would be helpful. The overall satisfaction question showed that half of the respondents showed satisfaction with the system, while 8.33% were unsatisfied with it.

5. CONCLUSION

This research developed a safety training system for Chinese metro construction workers. The training system is web-based and includes modules to evaluate the safety attitude and safety knowledge of construction workers. The core module is the question bank, which consists of over one thousand questions presented in a visual language. It is believed that visual language helps workers to understand and memorise safety behaviour. The questions came from two sources, regulations and codes and on-site patrol photos. The regulations and codes were carefully designed into illustrative cartoons. Together with over 6000 patrol photos, these illustrative cartoons were categorised and processed into questions for the question bank. The training system also prompts behaviour correction by providing explanations to each question, and it provides results analysis and statistics for managers.

A preliminary training session was conducted on a metro construction site. The attendees used the training system, and gave feedback on their satisfaction with a satisfaction questionnaire and interviews. Results showed that they are generally satisfied with the system, suggesting that the system was "easy to use", "functionally clear" and "met the requirements of their work". However, this research is at an early stage, and future work includes integrating scheduling with the safety training system and automated unsafe behaviour detection and correction.

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ASSESSING THE IMPACT OF BUILDING INFORMATION MODELING (BIM) ON CONSTRUCTION PROJECT PERFORMANCE

Mounir El Asmar, Ph.D.
Assistant Professor, Arizona State University, Tempe, AZ, USA, asmar@asu.edu

Tober C. Francom
Graduate Student, Arizona State University, Tempe, AZ, USA, tfrancom@asu.edu

Abstract

The use of Building Information Modeling (BIM) processes has been growing in the Architecture/Engineering/Construction (AEC) industry this past decade. As more and more companies make use of BIM, research studies are documenting its impact on key performance indicators utilized in the AEC industry. For example, one study presented BIM's financial return on investment (ROI) by comparing costs and savings accomplished through using BIM, while also highlighting reductions in numbers of requests for information and change orders for the projects using BIM. While previous research mostly focused on cost benefits, BIM also offers improvements to other key performance indicators. Previous studies listed six project-level outcomes that effective use of BIM might affect: safety, facility function, cost, schedule, sustainability, and globalization. However, BIM's impact on these project-level outcomes has not yet been verified using quantitative project data. This study evaluates the performance of 33 completed projects by statistically testing the impact of varying levels of BIM use. First, the literature was analyzed to identify important BIM characteristics as well as key project performance indicators, which then helped in the development of a data-collection survey to gather data for (1) BIM characteristics to use as inputs, and (2) quantitative performance indicators to use as outputs. Statistical data analyses were conducted to compare performance between the projects using BIM and those that are not. The preliminary findings were three-fold: projects using BIM exhibited a statistically significant improvement in safety metrics, micro-level schedule metrics, and metrics that affect facility function and cost. These results provide a more comprehensive understanding of BIM benefits by identifying particular key performance indicators that are affected by these processes. The AEC industry can use the findings of this study to help guide decisions regarding BIM investments in order to seek the identified benefits on their projects.

Keywords: BIM, building information modeling, performance metrics, statistical testing.

1. BACKGROUND

There are many different definitions of Building Information Modeling (BIM). Eastman et al. (2008) states a building information model contains precise geometry and relevant data needed to support the design, procurement, fabrication, and construction activities required to realize the building. Azhar (2011) builds upon this definition by stating a building information model is a model that characterizes the geometry, spatial relationships, geographic information, quantities, properties of building elements, cost estimates, material inventories, and project schedule.

The use of BIM in the Architecture, Engineering, and Construction (AEC) industry has been growing steadily over the past decade, with a rapid increase in the past few years. According to a study undertaken by McGraw-Hill (2009), even as the design and construction industry confronted a sluggish economy, most BIM users saw positive paybacks from their use of the technology. According to the report, users gain benefits that enhance productivity, improve their ability to integrate teams and give them an edge over the competition.

The use of BIM has provided a means for increasing total project quality, providing accurate scheduling timetables, yielding quantity take-offs, and diminishing total project costs (Eastman et al. 2008). However, many in the AEC industry have not adopted BIM due to the high initial capital cost, which includes software, training, time, and additional personnel. Additionally, another issue holding many industry professionals back is the lack of empirical data to prove these benefits.

In 2004, the National Institute of Standards and Technology (NIST) published a report stating that poor interoperability and data management costs the construction industry approximately $15.8 billion a year, which is approximately 3% to 4% of the total industry size (Issa et al. 2009). BIM might have the potential to decrease this value substantially. Kunz and Fischer (2012) listed six project-level outcomes that the effective use of BIM might impact: safety, function, cost, schedule, sustainability, and globalization. However, statistical testing of quantitative performance data is still necessary to prove BIM's impact on the aforementioned project-level outcomes.

An extensive review of the relevant literature was performed to analyze the current body of knowledge available regarding the benefits of using BIM. The goals of the literature review were to: (1) compile BIM inputs and performance outputs, (2) determine the empirical data and analysis that has been performed to assess BIM impact on performance, and (3) identify gaps in these analyses. To summarize the review of literature, most studies provide some evidence of positive BIM impact through qualitative evaluations of BIM performance. Very few studies collected actual project data to compare projects using BIM to those that did not use BIM. Such existing studies only looked at a relatively small number of projects where limited performance data was available. The hypothesis that BIM helps improve performance on construction projects is not yet supported by statistical analysis. This study serves as a first step towards quantitatively and statistically analyzing the benefits of BIM on project performance.

Without strong empirical data that supports the effectiveness of BIM on construction projects, numerous owners, architects, engineers, and contractors cannot rely on previous project data to inform their decision. One of the biggest challenges in studying BIM's impact is the reliance on anecdotal studies and results from qualitative questionnaires that are currently being used to compare the usage of BIM. The literature is rich with this type of studies; however, there are still unanswered questions regarding the direct BIM impacts on a project. In order to make a business decision for those companies that have not yet rolled out their BIM programs, there must be quantifiable data and proven benefits. Potential future benefits and investments regarding entire organizational implementation, rather than project implementation, cannot be measured prior to acceptance. The results of this study can help organizations seeking to quantify the impact of BIM.

2. OBJECTIVES AND METHODOLOGY

The objective of this paper is to empirically analyze data from projects with varying levels of BIM use. The methodology of this study consisted of 4 major phases: 1) Literature Review, 2) Survey Development, 3) Data Collection, and 4) Data Analysis. These phases can be seen in *Figure 1* and will be described in detail below.

A comprehensive literature review was conducted to analyze the key BIM variables, as well as major project performance metrics. The BIM characteristics or input variables were collected from several studies (e.g. Kunz and Fischer 2012; Kreider et al. 2010). Kunz and Fischer (2012) also grouped the output variables into six key performance areas. Since identifying the key variables and performance metrics provides guidance about the type of data that needs to be collected, the completion of the first phase serves as a solid basis for the survey development. The survey was designed to gather data on quantitative and qualitative performance metrics. It was shared with industry participants, specifically the general contractor or construction manager of each targeted project, to allow for the gathering of data in a consistent format. Data was received for 33 construction projects that have adopted BIM at various levels.

After the data was collected, the data analysis for this study consisted of three steps: building the correlation matrix, testing for normality, and conducting univariate analyses. First, a correlation matrix of the dataset was developed to highlight correlations between BIM inputs and project performance outputs. The use of the correlation matrix helps narrow down the large dataset in order to focus the analysis on the variables that exhibit at least a moderate correlation coefficient between them. Buda and Jarynowksi (2010) considered the relatively high correlated variables as those with an absolute value greater than 0.5. Additionally, the values that had an absolute value between 0.30 and 0.49 were considered to be moderately correlated and were also analyzed for this study. The correlation matrix was then converted to a heatmap in order to visually show these correlated variables; an excerpt of the correlation heatmap is shown in *Table 1*.

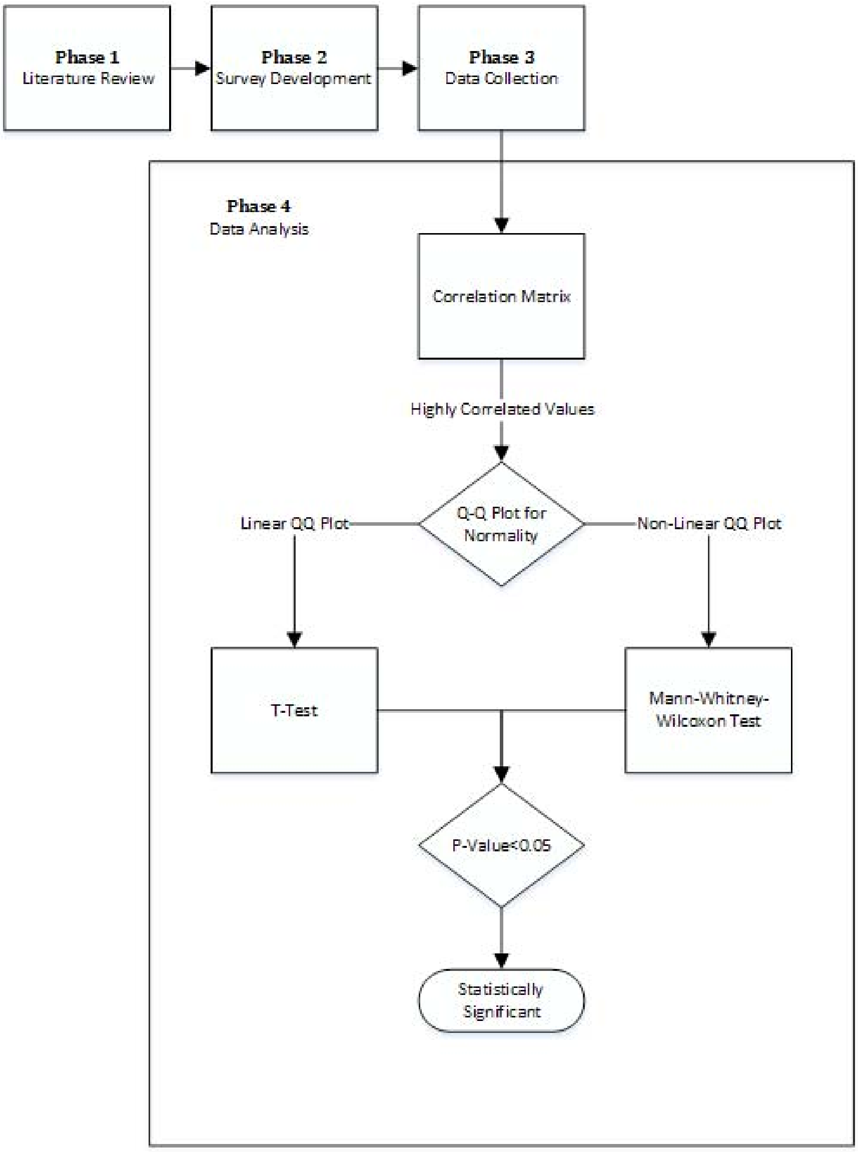

Figure 1: Research Methodology

The lists of BIM inputs and performance outputs were based on the literature review; the variables specifically shown in *Table 1* are defined as follows:

– BIM Reliance is the ability of the project team to contractually rely on the use of BIM for design and construction. Unlike most construction projects where 2-dimensional plans and specifications are used to construct the project, the definition of projects that rely on BIM consists of their ability to legally use the 3D model instead of the 2D drawings.

– BIM Use for Validation allows the project team to validate the constructability of the design. It also can be used to better predict if a project can achieve the budget requirements.

– BIM Use for Collaboration allows all the project team members to use the same model and change their respective trades and designs.

– BIM Use for Clash Detection is a process in which clash detection software (e.g. Navisworks) is used to determine field conflicts by comparing 3D models of different building systems. The goal of clash detection is to eliminate the majority of conflicts prior to installation (BuildingSMART Alliance 2011).

– BIM Infrastructure is a variable that highlights the project team's physical readiness for BIM use. This variable is the combination of the project team's contractual reliance on BIM, presence and use of BIM protocols for the project, and existence of joint servers dedicated to BIM.

– BIM Potential is the project team's potential to effectively utilize BIM on a construction project. This variable consists of a combination of the project team's BIM infrastructure and BIM experience, which includes gauging how much experience with BIM the key project stakeholders have previously had.

– The BIM Intensity variable gauges the overall level of BIM use on the project, and is computed by combining the variables denoting BIM potential (discussed above) and BIM use, which includes the facility systems for which BIM was used, what type of functions the model was used for, and the extent of BIM use.

The heatmap of correlations displays darker colors for variables that exhibit larger correlation coefficients. Dark green and dark red represent values that are moderately or highly correlated and that were analyzed further. Tests for normality (quantile-to-quantile plots) were performed to help determine which statistical analyses are most adequate. For each metric, one of two types of analysis was used: (1) t-tests were used when the dataset was found to be normally distributed, otherwise (2) the non-parametric Mann-Whitney-Wilcoxon (MWW) tests were used. The next section presents a discussion of the results.

Table 1: Correlations between BIM inputs and project performance metrics

Performance Outputs	BIM Inputs						
	BIM Reliance	*BIM Use for Validation*	*BIM Use for Colla-boration*	*BIM Use for Clash Detection*	*BIM Infra-structure*	*BIM Potential*	*BIM Intensity*
Construction Schedule Growth	-0.16	-0.19	-0.05	0.11	-0.01	-0.14	-0.07
Delivery Schedule Growth	-0.22	-0.31	-0.06	-0.33	-0.39	-0.18	-0.05
Number of RFIs	-0.05	0.29	-0.20	0.26	0.11	0.15	-0.04
RFI Processing Time	-0.30	0.14	-0.36	-0.08	-0.28	-0.16	-0.30
Changes	-0.03	0.26	0.13	0.52	0.31	0.30	0.11
Change Order Processing Time	-0.32	0.09	-0.21	0.09	-0.20	-0.08	-0.30
Rework	0.38	0.09	0.28	0.14	0.42	0.48	0.36
Punchlist Items	-0.31	-0.13	-0.15	0.03	-0.37	0.07	-0.17
Warranty Cost	-0.46	-0.29	-0.27	-0.26	-0.45	-0.32	-0.23
Latent Defects	-0.41	-0.54	-0.03	-0.28	-0.38	-0.38	-0.25
As-Built Quality	0.28	0.16	0.43	0.17	0.34	0.12	0.39

3. PRELIMINARY FINDINGS

The section investigates the effect of BIM on key performance criteria areas discussed in the literature. BIM use was compared for each performance metric individually using a univariate analysis. Data was available for metrics spanning four of the six performance areas discussed in the literature: facility function and cost, schedule, sustainability, and safety. *Table 2* presents a summary of the preliminary results.

Table 2: Results of the Preliminary Analysis

					Sensitivity Analysis P-Values (Tests 1,2,3)
BIM Inputs	**Performance Outputs**	**Test 1**	**Test 2**	**Test 3**	**Analysis**
BIM Use for Clash Detection	Warranty Costs and Latent Defects	0.096	0.053	0.033	MWW
BIM Use for Validation	Latent Defects	0.083	0.102	0.008	MWW
BIM Use for Collaboration	RFI Processing Time	0.161	0.023	0.023	MWW
BIM Reliance	Number of Recordable Injuries	0.015	-	-	MWW
	Warranty Costs	0.046	-	-	MWW
	Number of Punchlist Items	0.066	-	-	MWW
	Warranty Costs and Latent Defects	0.014	-	-	MWW
	Change Order Processing Time	0.0062	-	-	T-Test
	RFI Processing Time	0.0305	-	-	T-Test

3.1. Facility Function and Cost

Cost and function of the facility are two performance areas identified in the literature as potentially impacted by BIM. Warranty costs and latent defects are part of these areas, which can cost significant resources and can also impact the function of the facility. Warranty issues are those that occur during the first year of occupancy of the building, while latent defects are defined as those issues that occur after the end of the one-year warranty period. Warranty costs are measured in percent of total construction cost. The first test conducted for the use of BIM for Clash Detection demonstrated a potential benefit in terms of warranty costs and latent defects, with a p-value of 0.033 (see *Table 2*), which is below the commonly used threshold of 0.05 and therefore the impact of BIM on this metric is considered statistically significant. A sensitivity analysis was completed to gauge the impact of how the responses were coded: Test 3 discussed above separated the "high BIM use" projects, on one side, from the moderate, little, and no BIM use on the other side. Comparably, another test (Test 2) separated the "high BIM" and "moderate BIM" use projects, on one side, from the "little" or "no BIM use" on the other side. Interestingly, the results from Test 2 were less significant, suggesting that high BIM use could provide considerably more advantages than moderate BIM use. Finally, Test 1 separated the high, moderate, and light BIM use projects, on one side, from the “no BIM use” on the other side. Similarly, the results from Test 1 showed even less significance than those of Test 2, suggesting that BIM use at any level does not necessarily offer a significant effect on warranty and latent defects. These preliminary results are left for the reader to interpret. The authors’ conclusions are that there seems to be a relationship between the amount of BIM use and the positive impact on performance. However, more data and analysis will be needed to confirm the above relationship.

The use of BIM as a validation tool also showed the ability to decrease warranty issues and latent defects, with a p-value of 0.008 when a high amount of BIM was used. Similarly to the previous sensitivity analysis discussion, this variable showed less significant differences when the BIM requirement for inclusion was reduces. Test 1 and Test 2 showed no significant effect on warranty and latent defects, as illustrated in *Table 2*.

Another input that caused a decrease in warranty costs and latent defects was the ability of the project stakeholders to rely on BIM. Statistical tests of this variable showed a significant decrease in warranty costs and latent defects, with a p-value of 0.014. This subsection presents quantitative proof that BIM has the ability to save post-project costs and potentially maintain the facility function by reducing the need for warranty or latent defect corrections. The next subsection investigates the schedule benefits of BIM.

3.2. Schedule

Data was collected for both macro-level schedule performance metrics (e.g. project speed) and micro-level schedule performance metrics (e.g. processing times). There was no significant effect of BIM on the macro-level metrics; however some of micro-level schedule metrics showed significant differences. The first is the average change order processing time, defined as the period of time between the initiation of the change order and the owner’s approval of the change order. The second metric is the request for information (RFI) average processing time, defined as the period of time between the initiation of the RFI and the owner’s approval of the RFI. BIM showed significant improvements for both of these metrics. The contractual ability of the project team to rely on BIM showed a decrease in both RFI and change order processing times. When the projects that rely on BIM were compared to those that cannot rely on BIM, the p-value for RFI processing time was 0.0305, indicating a statistically significant difference between projects relying on BIM and those that are not. Similarly, the p-value when testing change order processing time was 0.0062, indicating BIM’s significant difference on change order processing times. These savings in time for RFI and change order processing times due to BIM reliance may be attributed to the ability of project stakeholders to approve these changes and requests directly on the BIM model, without having to document these separately since they are contractually allowed to completely rely on the BIM model for the project.

Another BIM input that seems to impact the RFI processing time is the use of BIM for collaboration. The resulting p-values were 0.023 when BIM was used heavily, and also when BIM was used at least moderately. However, these results do not hold when comparing any BIM use versus no BIM use; the process needs to be used “at least moderately” in order to see the benefits in shorter processing times. In summary, BIM has the potential to decrease RFI and change order-processing times on construction projects. These benefits are possibly associated with the contractual reliance and collaboration potential through the BIM model, which allow the major stakeholders to use the same model as a basis for project decisions.

3.3. Sustainability

Data was available for two environmental sustainability performance metrics: the tons of waste produced and the percent of materials recycled on a construction project. These performance metrics were plotted versus the overall level of BIM used on the project, as shown in *Figure 2* and *Figure 3*. The level of BIM use on the x-axis takes into account all the BIM factors for which data was available, including the extent of BIM use of each major building system, the BIM experience of each key stakeholder, the BIM infrastructure available and the functions for which the BIM model was used (e.g. clash detection, visualization).

The figures show a trend of decreased amounts of construction waste and increased recycling on projects that utilize BIM; however, the R^2 values are fairly low, meaning the BIM variable alone does not explain all the variation in performance. This uncovered trend is interesting and warrants further analysis. A future research study could focus solely on uncovering the impact of BIM on AEC projects’ environmental sustainability, by collecting data from a larger dataset in order to validate the trend uncovered in this study. Potential synergies with this relationship are that BIM allows for: (1) an increase in prefabrication, resulting in less construction waste, and (2) a better understanding of the project material flows resulting in improved planning and more recycling. Conversely, one could argue that more progressive owners, who are more likely to use BIM, are also more prone to care about the environmental sustainability aspects of their projects. The preliminary results presented in this section certainly indicate the need for more research to validate the discussed trends and theories.

3.4. Safety

Project data was available for the total number of Occupational Safety and Health Administration (OSHA) recordable injuries, which were used to calculate the incidence rates. When the projects that relied on BIM were compared to those that did not rely on BIM, the p-value for the difference in the number of recordable injuries was 0.015, indicating statistically significant differences. Similarly to the sustainability metrics above, this study only measured one safety metric on a dataset of 33 projects. The analysis shows significant differences in safety performance, and can be used as a basis for future research that tackles a comprehensive array of safety metrics collected from a larger dataset in order to generalize these findings.

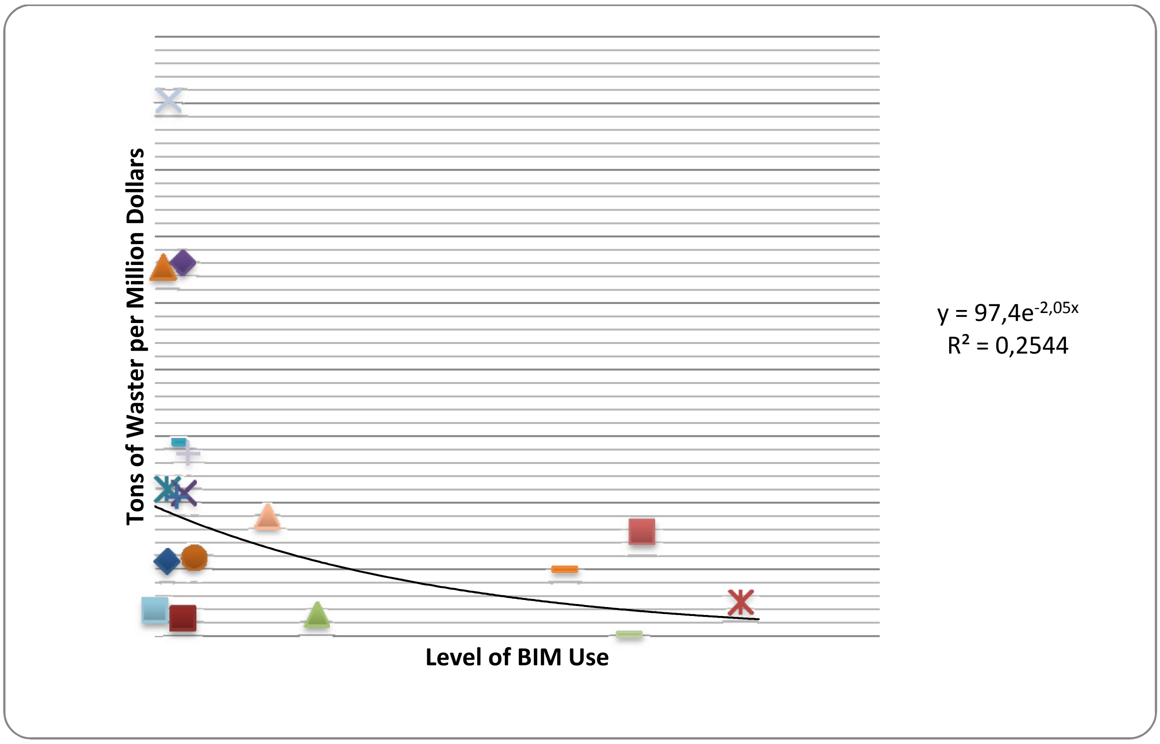

Figure 2: Tons of Construction Waste vs. Level of BIM Use

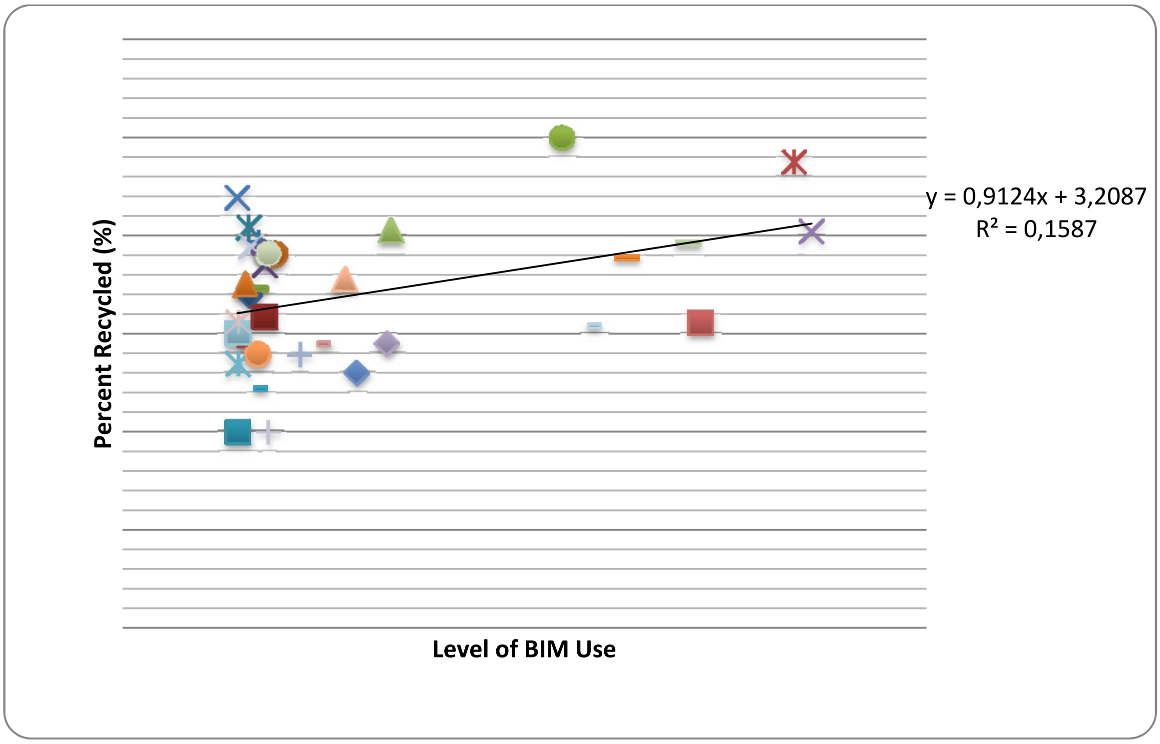

Figure 3: Percent of Construction Waste Recycled vs. Level of BIM Use

4. CONCLUSION

This study builds on the current BIM literature by providing a more quantitative understanding of BIM performance through collecting project data and presenting statistical analyses to relate specific project performance metrics to the level of BIM use. Projects utilizing BIM displayed performance benefits in four of the six performance areas discussed in the literature as potentially being impacted by BIM: facility function and cost, schedule, sustainability, and safety performance. For instance, the use of BIM demonstrated significant reductions in warranty costs and latent defects as well as significantly faster processing times for change orders and RFIs.

The results presented in this paper are part of an ongoing research effort. The next step is to build on this univariate analysis by performing a multivariate data analysis for all key BIM characteristics and performance metrics. Moreover, the results of this study specifically stem from a dataset of complex vertical construction projects. Future research efforts will expand the analysis to cover a larger dataset that includes a wider variety of projects.

This research study offers a contribution to the construction engineering and management literature and to the AEC industry by demonstrating quantifiable BIM performance benefits. The results can be used to guide project stakeholders in making better-informed decisions regarding BIM investments and impacts.

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DEVELOPING THE CONSTRUCTION PROJECT QUARTERBACK RATING: AN INNOVATIVE PROJECT PERFORMANCE METRIC

Mounir El Asmar, Ph.D.
Assistant Professor, Arizona State University, Tempe, AZ, USA, asmar@asu.edu

Awad Hanna, Ph.D.
Professor, University of Wisconsin-Madison, Madison, WI, USA, ashanna@wisc.edu

Abstract

Performance metrics utilized by the sports industry provide benchmarks to compare athletes. For example, the passer's rating used in the U.S. National Football League (NFL) is calculated by combining four values for each quarterback: completion percentage, passing yardage, touchdowns, and interceptions. This combination leads to a single number that is used to compare the comprehensive performance of NFL quarterbacks. The Architecture, Engineering, and Construction (AEC) industry, although four times larger than the sports industry, does not have overall performance ratings that are as widely used. AEC projects are unique, highly complex, and normally require several performance dimensions to achieve success. This paper presents the development of an innovative comprehensive performance metric, similar to the quarterback rating in the NFL, specifically developed for construction projects: the Project Quarterback Rating (PQR). PQR combines the key performance metrics of a construction project into a single number to facilitate project comparisons and provide a basis for quantifying project success. The performance areas combined include: customer relations, safety statistics, schedule and budget compliance, project quality metrics, financial results, communication and collaboration between the different project stakeholders. Data was collected from several industry professionals across the U.S. and multivariate data analysis techniques were used to validate the model. The PQR can be used to compare overall performance for different projects, but it can also serve additional purposes. One such example that showcases the potential of PQR is comparing the performance of delivery systems. In this paper, PQR scores were calculated for projects completed under different delivery systems, and the results clearly show the superiority of the more integrated delivery systems when compared to projects completed under more traditional delivery systems.

Keywords: Construction management, mathematical modeling, performance metrics, project assessment tools.

1. BACKGROUND

This paper introduces the Project Quarterback Rating (PQR), which combines the key performance metrics of a project into one number to facilitate the comparison of projects in the Architecture, Engineering, and Construction (AEC) industry and provide a basis for quantifying project success. The performance of a project often cannot be measured by one performance metric, such as cost, schedule, or safety. It involves additional metrics, such as customer relations, profit and return business, and the quality of the built facility. Similar to the NFL quarterback rating in the U.S. sports industry, the authors attempt to combine these metrics and others into one value that represents the performance of a given project. To increase the potential for the implementation of this model in the construction industry, the PQR was developed as a linear function that acts as a weighted average of the several key performance metrics on AEC projects. Use of the model provides a baseline on which projects can be compared, as well as a venue to discuss project success. After development and testing, PQR was used to compare the performance of several projects grouped based on their delivery systems. Design-Build (DB) performance has been compared to that of Construction Management at Risk (CMR) and Design-Bid-Build (DBB) (Konchar and Sanvido 1998). Similarly, Integrated Project Delivery (IPD) performance has been compared to that of other more mainstream delivery systems (El Asmar and Hanna 2013) based on individual key performance metrics. However, PQR allows for the combination of all the identified performance metrics and the comprehensive comparison of a single new metric that illustrates overall project performance. The PQR model is developed to serve as a tool that helps analyze and improve project performance.

A myriad of performance metrics have been used to assess construction project success. The metrics studied by Molenaar (1995 and 1999) included quantitative measurements of cost and schedule growth, as well as qualitative measurements of quality with respect to the user's expectations, construction administrative burden, and owner satisfaction with the overall project. Pocock (1996) added design deficiencies and modifications to the list of metrics. Songer et al. (1996) studied several metrics, including the number of claims. Konchar and Sanvido (1998) measured unit cost, construction speed, delivery speed, intensity, cost and schedule growth, turnover quality and systems quality. Chan et al. (2002) also included project profitability, technical performance, productivity, and environmental sustainability. Menches and Hanna (2006) developed a performance measurement index that includes actual percent profit, percent schedule overrun, amount of time given, communication between team members, budget achievement, and change in work hours. Rankin et al. (2008) identified a set of performance metrics for measuring performance of the Canadian construction industry. The authors combined metrics for both the construction phase and for an extended timeline of building life. In doing so, they covered seven performance areas: cost, time, scope, quality, safety, innovation, and sustainability. The project performance literature is rich in studies that focus heavily on schedule and cost performance metrics, while largely disregarding the remaining performance metrics. It is only recently that the industry has stressed on the importance of quantitatively measuring several additional variables.

2. PROBLEM STATEMENT AND RESEARCH METHODOLOGY

The literature review uncovered that a comprehensive project performance metric for construction projects does not exist. The Project Quarterback Rating (PQR) is developed to address this research opportunity. Many performance metrics were identified throughout the literature, and were combined into a comprehensive metric that gauges overall project performance. The focus of this paper extends beyond the commonly analyzed metrics of cost and time to include safety and quality, as well as less commonly studied metrics, such as changes, process inefficiencies, communication, and profit. PQR complements the literature that compares project delivery systems. Alternative and integrated delivery methods, such as CMR, DB, and IPD, have been shown to improve project performance based on individual metrics (e.g. unit cost and delivery speed) when compared to the traditional DBB delivery system. However, no studies have combined all key metrics into one comprehensive project performance metric to test the overall performance of these delivery methods. The development of the PQR offers an opportunity to contribute to the delivery systems literature by comparing delivery methods using one comprehensive metric.

For the purpose of this study, a data-collection survey was developed and then used to collect project performance data from industry participants, specifically the general contractor or construction manager of each targeted project. The survey requested specific data regarding project performance and allowed for an intense data collection effort targeting performance metrics for individual construction projects. A separate section of the survey was designed specifically to ask respondents to independently define factors or metrics that they consider when assessing the success of a project. Thirty-four different respondents addressed this question. Their responses were grouped in related performance areas (e.g. safety, cost, and quality), for which the frequencies were calculated and then converted into percentages that add up to 100%. *Figure 1* shows the seven performance areas identified. The metric related to customer relations and return business was present in most of the responses for this section of the survey. This performance area scored surprisingly higher than the traditional performance areas of cost and schedule. Safety performance ranked second and schedule performance a close third. Project cost metrics ranked in fourth place, with quality performance and financial profit in very close fifth and sixth places. Lastly, communication and collaboration metrics were identified as the seventh key performance area for AEC project success.

3. THE PROPOSED PQR FUNCTION

The seven performance areas identified by the survey respondents and discussed in the previous section are combined into the PQR function. These are: (1) customer relations, (2) safety, (3) schedule, (4) cost, (5) quality, (6) profit, and (7) communication. The model computes for each project j a corresponding Project Quarterback Rating $\mathrm{PQR_j}$. The PQR score is based on the seven evaluation criteria with different weights for each. To mathematically describe the model that calculates $\mathrm{PQR_j}$, the following notation is used:

$$\mathrm{PQR_j} = \sum_{i=1}^{I} \mathrm{w_i\, s_{ij}}$$

In this notation, $\mathrm{w_i}$ is the weight of performance area i, such that $1 \leq \mathrm{i} \leq \mathrm{I}$ and $\mathrm{I} = 7$, and $\mathrm{s_{ij}}$ represents the composite score of project j for performance area *i*. In this function, the performance score $\mathrm{PQR_j}$ is calculated as the weighted average of the different performance areas $\mathrm{s_{ij}}$. The rationale behind using a linear model lies in its simplicity and the fact that it allows for the addition of several performance metrics. The underlying assumption here is that an overall comprehensive project performance rating $\mathrm{PQR_j}$ exists and only depends on the performance areas *i*. Moreover, these scores $\mathrm{s_{ij}}$ for each of the seven areas also combine many components; for instance, project cost combines the final unit cost and the cost growth as compared to the initial cost estimates. The term $\mathrm{X_{ijk}}$ denotes the original scores of performance metrics, with $1 \leq \mathrm{k} \leq \mathrm{K_i}$ and $\mathrm{K_i}$ representing the number of metrics combined in each performance area i. For example, if i represents the cost performance area, then $\mathrm{X_{ijk}}$ would represent unit cost and cost growth ($\mathrm{K_i} = 2$), which will be combined into $\mathrm{s_{ij}}$ that represents the cost performance area, as shown in the middle part of *Figure 2*. *Figure 2* exhibits three levels: (1) $\mathrm{PQR_j}$ is the top level; (2) $\mathrm{s_{ij}}$ is the second level and includes the seven performance areas that are combined; and (3) $\mathrm{X_{ijk}}$ represents the individual performance metrics listed under each of the seven areas.

After looking at all these metrics, a problematic issue becomes evident: one cannot add together values for metrics with different units, such as cost and time. This is also true within the same performance area. For example, unit cost is measured in dollars per square foot, and cost growth is measured in percentage terms. Standardization is an effective solution to this problem and can transform any set of numbers to their equivalent values with respect to the standard normal distribution, by outputting the number of standard deviations above or below the average for the metric at hand. Standardization also presents an additional advantage by allowing for a straightforward interpretation of results: positive values indicate above average performance; negative values indicate below average performance; a value of zero indicates average project performance. The normalization procedure maps each original score $\mathrm{X_{ijk}}$ to a normalized version $\mathrm{z_{ijk}}$. The mean score and standard deviation are calculated for each specific metric k in each performance area i, as follows:

$$\mathrm{\mu_{ik}} = \mathrm{Av_{ik}}\left(\mathrm{X_{ijk}}\right)$$

$$\mathrm{\sigma_{ik}} = \sqrt{\mathrm{Av_{ik}}\left(\left(\mathrm{X_{ijk}} - \mathrm{\mu_{ik}}\right)^2\right)}$$

The z-scores are then calculated to be $\mathrm{z_{ijk}} = \left(\mathrm{X_{ijk}} - \mathrm{\mu_{ik}}\right)/\mathrm{\sigma_{ik}}$. These z-scores hide any variation of the ranges and units of different metrics, giving them equal effect on $\mathrm{s_{ij}}$ (until the weights $\mathrm{w_{ik}}$ are applied). The scores for each performance area can be calculated using the equation: $\mathrm{s_{ij}} = \sum_{k=1}^{K_i} \mathrm{w_{ik}\, z_{ijk}}$. Here $\mathrm{w_{ik}}$ denotes the weight of each metric within a specific performance area i. The z-scores $\mathrm{z_{ijk}}$ are centered around zero; some values are positive and some are negative. After being used in the weighted average, a similar normalization technique is used to standardize the resulting scores s_{ij}. Since the mean of all s_{ij} is zero, each s_{ij} is directly divided by the standard deviation of all s_{ij}, similar to what was completed previously for the original performance metrics scores.

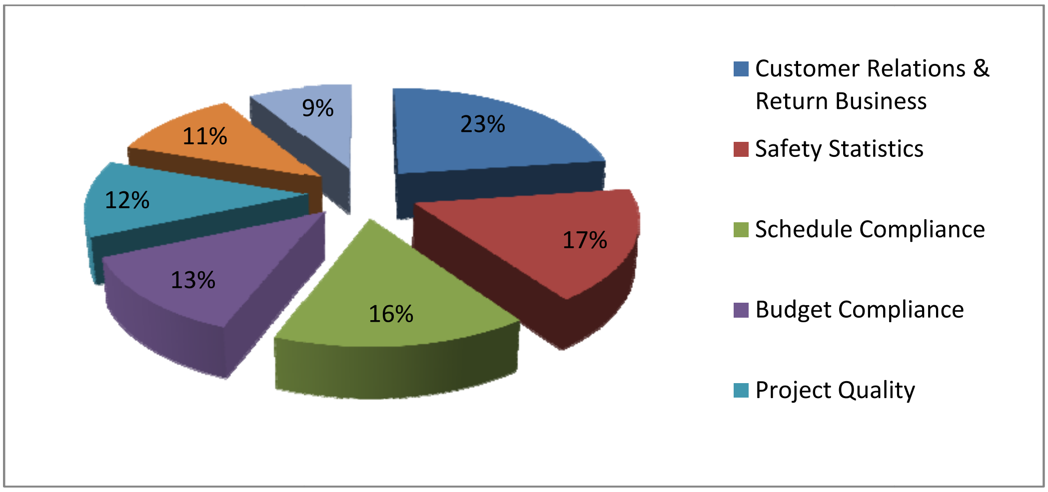

Figure 1: Respondents Averages for Performance Area Percentages

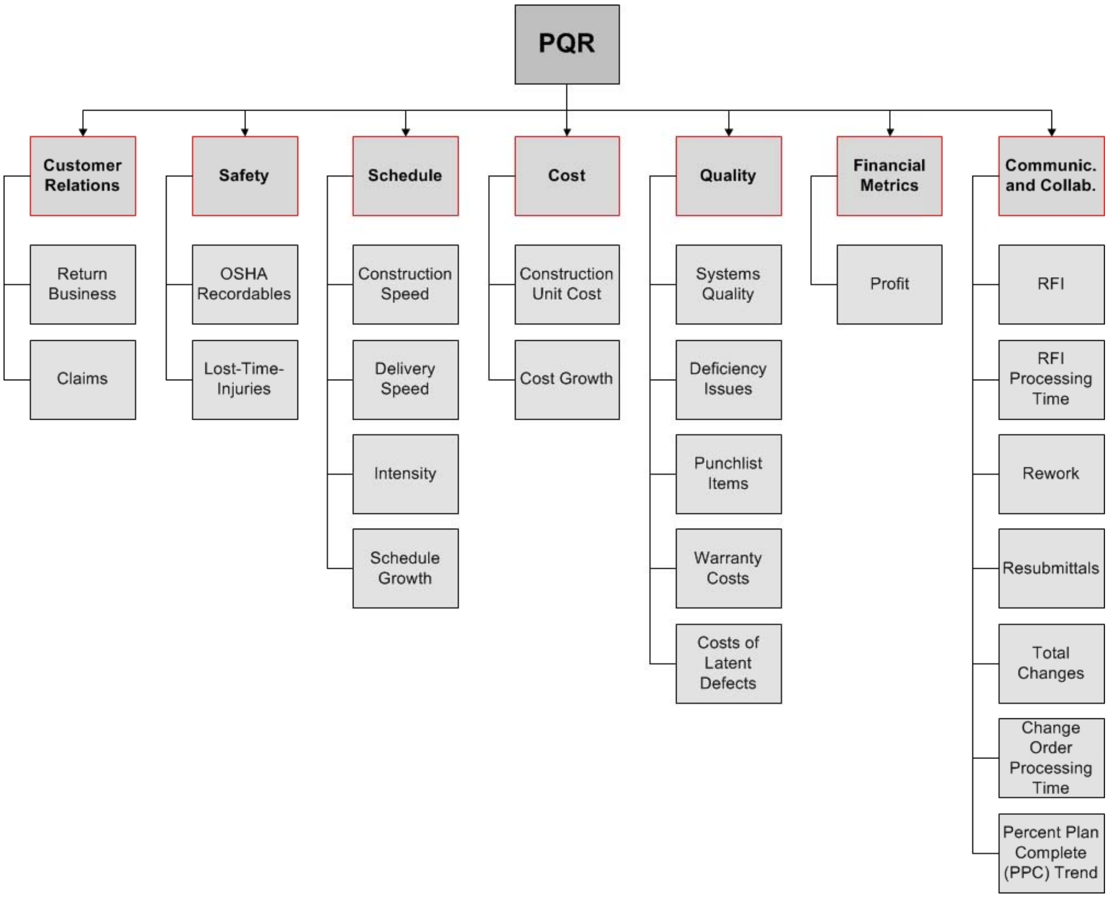

Figure 2: PQR Structure

The resulting z-scores of $\mathrm{s_{ij}}$ will ensure a straightforward interpretation of the results, similar to what was discussed earlier: a negative score means the project had a lower-than-average performance for that specific area and a positive score means the project had an above-average performance, while a score of zero means the project had an average performance. Furthermore, the values above or below average again can be interpreted as numbers of standard deviations relative to the average.

After the transformations, the standardized scores for the seven performance areas were then combined into the PQR formula presented earlier, $\mathrm{PQR_j} = \sum_{\mathrm{i}=1}^{\mathrm{I}} \mathrm{w_i}\, \mathrm{s_{ij}}$. The resulting scores underwent one last standardization procedure to warrant the interpretation presented above.

After developing the framework for the PQR function, the authors populated it with actual project data to render it into a function that can be used for assessing overall project performance. Generous industry collaborators granted access to 35 projects representing DBB, CMR, DB, and IPD. All projects were completed between 2005 and 2012, and most were private sector projects. The total dollar amount of construction work for all projects combined was around $3 billion U.S. Dollars. The cost distribution included project costs from $5 million to $400 million U.S. Dollars. The types of projects were generally large-scale high-complexity institutional facilities, such as hospitals and research laboratories. Therefore, the results of the study mostly apply to the above type of projects; however, the developed framework can be replicated for different types of construction, such as highway or industrial projects. The proposed model can be used as-is for benchmarking projects, or as a framework where users can adjust the variables and percentages based on specific needs and success factors of their own unique projects.

The PQR model presented based on this study's dataset is as follows:

$$\mathrm{PQR} = \frac{\begin{array}{c}0.23 * \mathrm{Relations} + 0.17 * \mathrm{Safety} + 0.16 * \mathrm{Schedule} + 0.13 * \mathrm{Budget} \\ +0.12 * \mathrm{Quality} + 0.11 * \mathrm{Profit} + 0.09 * \mathrm{Communication}\end{array}}{0.51}$$

The 0.51 value in the denominator is the standard deviation of all project scores that ensures the standardization of the PQR function. The scores for each of the identified performance areas needed to be standardized individually in order to be used in the PQR formula. A score was computed for each of the performance areas present in the PQR function, and was used in the PQR function to obtain an overall performance rating for each project. A user can apply this exact formula to his or her project, and the project's PQR can be interpreted relative to the scores of the 35-project database compiled for this study. That is, if the PQR is positive, then the project is above the average performance of the projects in this study. However, other users might have their own large dataset of projects and might want to create their own formula based on their respective dataset. In that case, the users can employ the same development technique discussed here, and the resulting coefficients could be slightly different depending on their set of projects and their respective performance.

After discussing how the seven performance areas can be linearly combined into the PQR, it is now appropriate to discuss how the scores can be computed for individual performance areas. Due to the page limit, this conference paper will only discuss one of the seven areas thoroughly, schedule performance, to provide an illustration of how the PQR function can be employed.

The schedule performance area was ranked third by the survey respondents in terms of overall importance for project success. Four performance metrics are combined into the schedule performance score: (1) construction speed, in square feet per day, (2) delivery speed, also in square feet per day, (3) construction intensity, in U.S. Dollars per day, and (4) construction schedule growth, in percentage terms between the initial schedule estimate and the actual schedule. Key quantitative schedule metrics can be relatively easily calculated because most project teams keep track of important project dates, such as the construction notice to proceed and substantial completion.

The mean for construction speed (C.S) was 331.50 square feet per day and its standard deviation was 259.40; while the range for the initial variables extended from 63.69 to 1348.68 square feet per day. The mean for delivery speed (D.S) was 210.09 square feet per day and the standard deviation was 169.85; while the range for the initial variables extended from 55.76 to 645.36 square feet per day. The mean for construction intensity was 102,794.94 U.S. Dollars per day and the standard deviation was 77,658.17; while the range for the initial variables extended from 22,052.34 to 395,124.00 U.S. Dollars per day. The mean for schedule growth was 12.50 percent and the standard deviation was 66.16; while the range for the initial variables extended from -23.23 to a staggering 329.35 percent.

Each of the four metrics was standardized individually, and each was given a weight of 25%. A weighted average of the four new z-scores is computed, and the result is standardized again. The formula can be devised with the value in the denominator representing the 25% weight of each metric multiplied by the standard deviation of their weighted average. The 2.86 value in the denominator equals the standard deviation 0.72 multiplied by four, since each member of the numerator accounts for one fourth of the total schedule score. Therefore, the formula for schedule performance can be written as:

$$\text{Schedule} = \frac{\dfrac{\text{C.S} - 331.50}{259.40} + \dfrac{\text{D.S} - 210.09}{169.85} + \dfrac{\text{Intensity} - 102{,}794.94}{77{,}658.17} - \dfrac{\text{Growth} - 0.125}{0.6616}}{2.86}$$

The negative sign before the construction growth value in the numerator will adjust the negative connotation of schedule growth and allow for its z-score to be added to metrics that need to be maximized, such as construction speed. There are no restrictions to use schedule values outside the range of the data collected to build this model. This equation can be used to calculate a project’s score with respect to its schedule performance, and the resulting score can be used in the third part of the PQR function presented earlier.

4. PQR APPLICATION EXAMPLE: TESTING IPD PROJECT PERFORMANCE

In a recently paper, the authors compared the performance of the emerging Integrated Project Delivery (IPD) system to that of more traditional delivery performance. These comparisons were based on individual metrics, and the results demonstrated that the emerging IPD system can offer a superior performance based on a number of metrics, and yet shows no performance differences for other metrics. Similarly, alternate delivery methods such as construction management at risk (CMR) and design-build (DB) have been shown to improve project performance based on individual metrics, specifically project cost and delivery speed, when compared to the traditional design-bid-build (DBB) delivery system. However, no studies have combined all key metrics into one comprehensive project performance metric to test the overall performance of delivery systems.

The development of the PQR offers an opportunity to contribute to the delivery systems performance literature by allowing for overall comparisons using one comprehensive metric. This paper will showcase one such example application by comparing Integrated Project Delivery (IPD) and non-IPD projects' overall performance. Provided that there are many definitions of what constitutes an IPD project, IPD is defined in this paper as a delivery system distinguished by a multiparty agreement and the very early involvement of key participants; i.e. before the design effort starts. The term *IPD-ish* describes projects that show several IPD attributes (sharing risk and reward, co-location of key stakeholders, existence of a *Core Group*, etc.) but do not use a multiparty contract.

The first step for this application was to compute PQR scores for all the projects in the database by using the equations presented earlier in the paper. IPD projects were then separated from non-IPD projects. The average PQR for IPD projects was 0.54, or more than half a standard deviation above the average project in the research database. The average PQR for non-IPD projects was -0.31, or about a third of a standard deviation lower than the average project in the database. *Figure 3* shows boxplots comparing the PQR for IPD and non-IPD projects. The visual difference between the two samples is clear, and what is also interesting here is that IPD-ish projects are behaving similar to IPD projects, on average, when it comes to overall project performance.

The second step was to perform statistical tests on the PQR data to determine if the observed differences in performance are statistically significant. The t-test is an analysis that can be used to assess the statistical significance of the difference between two sample means. In general terms, a t-test is optimal when each population in the dataset is normally distributed (Lehmann 2006). Normality tests were conducted, showing the PQR data can be assumed normally distributed, and then t-tests were performed on the data. The tests resulted in a p-value of 0.009, which is considered very significant even at the strict 0.01 significance level, presenting further evidence that IPD projects realize superior performance.

5. CONCLUSION

This paper discusses the development of PQR as a comprehensive performance metric for AEC projects. Forthcoming publications by the same authors will expand the discussion to include detailed discussions of all seven performance areas outlined in this paper, validate the PQR function using different multivariate data analysis techniques, and expand the application of PQR to further assess the effect of individual delivery systems and their level of integration on overall project performance.

The PQR function in its proposed form mostly applies to complex vertical construction projects, and the limitations of this developed function lie in the scope of this study and the dataset received from the generous organizations that were willing to share their project performance data for research purposes. PQR can be used to benchmark and compare AEC project performance, but it also can be adjusted and used internally by AEC organizations to gauge their own projects and seek areas for improvements.

There is an endless potential for PQR to gauge performance. One such example was presented in this paper: assessing the overall performance for emerging project delivery systems. PQR scores were calculated for AEC projects, and then a statistical analysis was completed and the results confirm that IPD projects have a superior overall performance as compared to non-IPD projects. This analysis contributes to the literature of project delivery performance, which typically relies on individual metrics, by offering a means for a comprehensive assessment through this new proxy for overall performance.

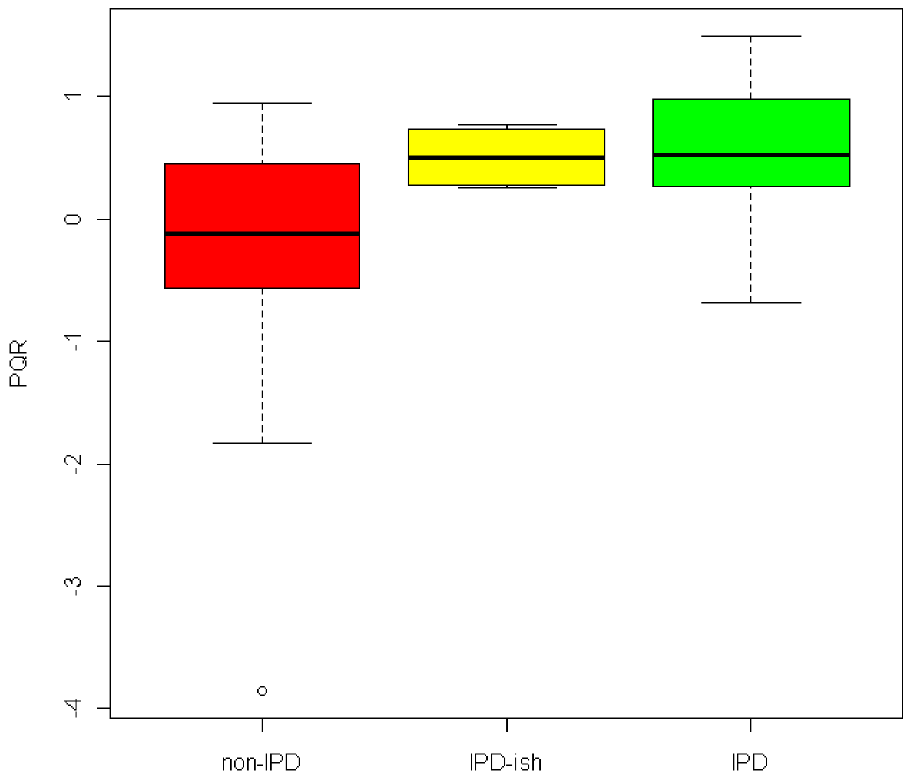

Figure 3: PQR Boxplots

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RAPID RETURN ON INVESTMENT BY INNOVATIVE METHODS IN CONSTRUCTION VISUALIZED BY CASH FLOW MODEL

Kazuyoshi Endo
Kogakuin University, Tokyo, Japan, endo@sin.cc.kogakuin.ac.jp

Thomas Bock
Technische Universität München, Munich, Germany, thomas.bock@br2.ar.tum.de

Thomas Linner
Technische Universität München, Munich, Germany, thomas.linner@bri.arch.tu-muenchen.de

Abstract

The introduction of innovative methods such as automation and robotics in construction improves productivity, quality and safety of construction. Due to economic downturn and lack of economic feasibility, the development of new machinery based on construction systems during the 1990s stopped prior to achieving the necessary Return On Investment (ROI). Therefore, the authors identified that it is necessary for innovative construction methods, that the owners or clients should demand an individual profit regarding to the building construction process. In the past, the manufacturing companies harvested the benefits of productivity improvement by innovative construction methods for cost reduction. The companies did not emphasize on the profit for the owners. In this paper, the authors analyze and visualize how previous applications of innovative construction methods on relatively large-scale construction sites, changed the cash flow of the project life. A simulation, analysis, and comparison of the trade-off of various effects to cash flow, by shortening the construction period despite an increase in cost by innovative construction methods, are proposed. An analysis is developed on how big the amount of the profit benefits has to be, in order to not just benefit to owners, but also cover the expenses for research, development and management operations required to develop and implement innovative construction methods. Techniques and methods from the financial engineering field are introduced in order to evaluate profit and expense margins. The authors are also aware of the risks involved in such an evaluation, by considering the fluctuations of the rent income to be provided from the finished building using the Monte Carlo technique. The aim of the proposed cash flow approach to innovative construction methods is to set up an economic framework in which technological development can exist. The outcome of the approach shall complement technological driven approaches to innovative on-site construction methods and later serve as a basis for future technically oriented research.

Keywords: discounted cash flow, Monte Carlo Technique, Net Present Value and Return on Investment.

1. OVERVIEW OF THE STUDY

1.1. Background and Objectives

The introduction of innovative methods such as automation and robotics in construction improves productivity, quality and safety. Due to economic downturn and lack of economic feasibility the development of new machinery based on construction systems during the 1990s stopped prior to achieving the necessary Return On Investment (ROI). Therefore, the authors identified as a major research question that for the expansion of market and individual profit, it is necessary for buildings owners to demand innovative construction methods. In the earlier years, the manufacturing companies harvested the benefits of productivity improvement by innovative construction methods for the purposes of cost reduction, without emphasizing owner related profit.

In this paper, the authors analyze and visualize how previous applications of innovative construction methods to relatively large-scale building construction site changed the cash flow of the project life. Additionally, a simulation, analysis, and comparison of the trade-off of various effects to cash flow by shortening the construction period despite an increase in cost by innovative construction methods, are proposed. An analysis on how big the amount of profit benefits have to be, in order to not just benefit to owners but also cover the expense for research, development and management operations necessary to develop and implement innovative construction methods.

1.2. Methods

Project worksheets are considered as well as calculations of the cash-in and the cash-out at each point during the project life. Furthermore, techniques from the financial engineering field, in order to evaluate profit and expense margins are utilized. The authors are aware of incurred risks in this evaluation, by considering the fluctuations of the rent income to be provided from the completed building using the Monte Carlo technique. The aim of the proposed cash flow approach in innovative construction methods is to set up an economic framework in which technological development can take place.

2. OUTLINE OF MODELING

2.1. Building typology

Initially, the building typology is defined, which is later analyzed in this paper. A new high or middle-rise apartment building with standard quality grade is considered for this analysis. This apartment is intended for renting and they will be located in Tokyo, Japan.

It is assumed that the building is completed by a standard construction method in a time frame of 20 months. The information about the term of work is quoted from the ``Council of Japan construction industry employees' unions´´ (2012).

The total sum of construction costs is defined at 250,000 yen/m^2. This yields approximately 2,000 euro/m^2 at an exchange rate in January 2013. This construction cost is taken from the database of the ``Japan Building Cost Information´´ (JBCI) 2012 published by the Construction Research Institute. JBCI comprises cost information announced for the feasibility study, planning and basic design stage of the building project by Construction Research Institute. This was compiled and analyzed statistically in real construction contracted prices, which were collected from construction companies and architectural design offices.

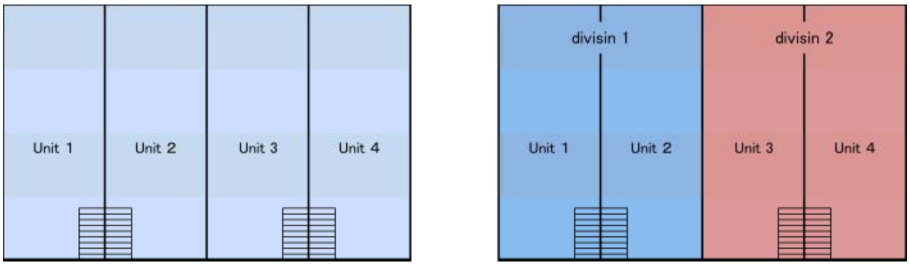
The authors define the rent income of this building from related information for customers on the website of properties for rent located in Tokyo, Japan. The rent is 250,000 yen / month for an area of approximately 70 m^2. It is 2,000 euros /m^2 at an exchange rate in January 2013.

In addition, all financial values in this paper make the total sum of the construction cost an index, i.e. 100. The cost of construction fixes it to the equivalence and observes the change of other variables even if using any method in this paper shortens the construction time frame.

2.2. Innovative construction methods Applied to Model

The construction period is reduced from a standard construction method (20 months) down to 15 months, 10 months and 5 months, by utilizing innovative construction methods. No specific construction methods are suggested for application to this model. The purpose is to quantify the influence the cash flow has on the whole project life. In other words, the purpose is to clarify the change of the Net Present Value (NPV) of the project by the proposed construction methods. On the basis of the above, the followings can be depicted regarding new construction methods proposed in this paper:

Initially, Ando et al. (1983) suggested multi-site scheduling presented in Figure 1. Using this approach the construction time was reduced by carrying out parallel activities into divide sites. This method has already been adapted to many actual projects in Japan.



Sequential activities *Parallel activities in divide sites*

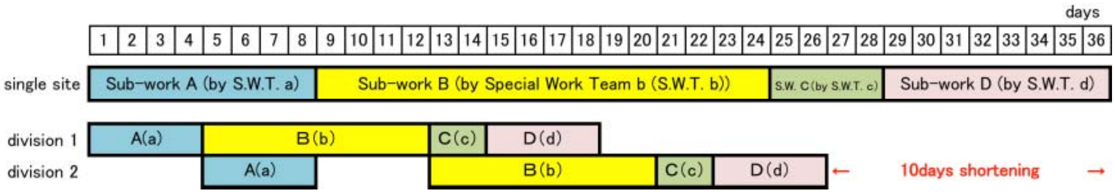


Figure 1: Effect of construction time reduction by parallel activities in divide sites

Figure 2 depicts such an example. Furthermore, the construction time can be dramatically shortened if all sub-works can be implemented on the same time reference. This construction method requires an increase in costs due to the higher management of the supply chain of materials and components, enhanced crane activity and the adjustment of the contract contents between some sub-contractors.

Figure 2: Example of parallel activities in divide sites

Secondly, Kanisawa et al. (2003) suggested the introduction of multi-skilled workers in real building construction sites. The skills of the construction workers were specialized to the scope of specific tasks, and this lead to the rigid Union shops in Germany, U.S.A. and Japan. The introduction of new methods to the building construction lowers their rate of operation and tends to disturb improvement of the productivity. Introduction of multi-skilled workers improves the productivity of fragmented works. It disturbs the spread to entail special costs for their upbringing.

Another construction method developed recently is the super-high-speed construction that Chinese company "Broad Group". According to the movie shown on their website (http://www.broad.com), they built a 30-storey hotel by a system which incorporated most of its facilities in the slab components beforehand, in only 15 days. In a big market such as China where economic development is remarkable, such a method of construction may spread to enable rapid ROI.

2.3. Model of the Cash Flow

Assuming the building models and applied techniques mentioned above, the authors describe the summary of the cash flow in the whole project life consisting of the design stage, construction stage, rental stage, and remaining value evaluations showed (Figure 3).

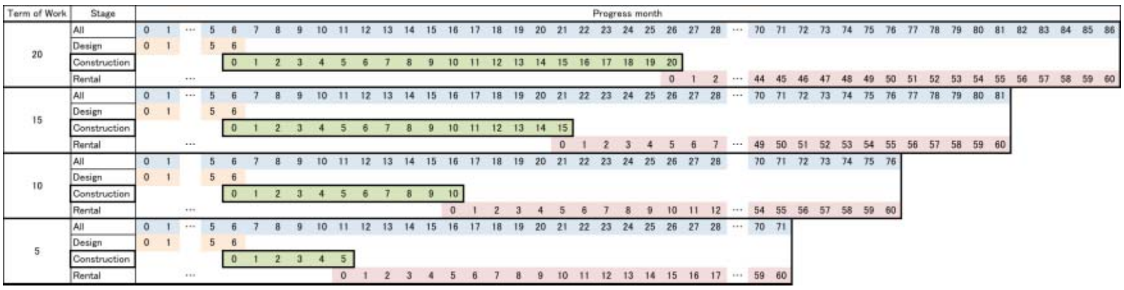


Figure 3: Model of project life

The discount rate for the monthly cash flow it is assumed at 1/12 of the annual discount rate. The standing point of the present value of the cash flow sets it at the time of the project start, i.e. month 0.

Design stage: It is supposed that this building is designed within 6 months and the involved designed costs comprise 10% of the construction costs. The authors contacted a contractor and a design office to make this model simple in the analysis of the cash flow. But this does not mean the design and build contract.

The design progresses every month during the design stage and the owner pays the design fee to the design office periodically every month. The sales amount gross profit rate of a design office sets it with 6.5%. If the discount rate is 0% on all project stages, this means that the design office's NPV would be 0.65. When the design office completes the design, this eventually costs 10. The design office pays the expense equally every month.

Construction stage: The sales amount gross profit rate of a contractor sets it with 6.5%. If the discount rate is 0% in the whole project life, this means that the contractor's NPV is 6.5. When the contractor completes the construction, it costs 100. Three during the term of work divides the payment for the works. This payment condition is based on some real contracts of apartment construction in Japan. The contractor pays the expense equally every month to sub-contractors, Material suppliers, etc.

– The owner pays 30% of the construction cost to the contractor at the beginning phase.

– The owner pays 30% of the construction cost to the contractor after 2/3 of the term of work.

– The owner pays 40% of the construction cost to the contractor at the completion of work stage.

Rental stage: This building is a configured apartment for rental purposes. The length of the rental stage is 60 months. The series of the rent incomes, change setting by simulations are mentioned in section 3. The details of the setting will be also explained in section 3.

Remaining value evaluations: The residual value of this building becomes zero after 20 years with the introduced discount on the fixed amount, on every month during the rental stage.

2.4. Matter to simulate

In this paper, the authors examine the following three points. These points are the consequences of shortening the term of work. In other words, it is confirmed how NPV of the project is thereby changed.

– The contractor can get the money for construction work earlier.

– The owner can start the rental stage earlier.

– The occurring fluctuations of owner's income in the rental stage due to the widely varying rates of vacancy over time.

In Japan, the shortness of pay back period of the project often becomes the important condition when banks provide a loan to an owner. The economical and the social environment of the construction projects significantly changed in the past time. Therefore the real profit to be provided from the project by time progress tends to considerably vary from the basic business plan. On a high-risk project, the shortness of the payback period may have priority over the maximization of the profit from it.

3. RESULT OF SIMULATION

3.1. Present Value of the Cash Flow

The cash flow during an assumed 5-months term of work project life based on the proposed method is given below (Table 1 and Figure 4). The cash in of the owner begins after entering the rental stage, once the building is completed. The contractor's NPV is 7.15 (=110*6.5%), as explained later. In this setting, the owner's NPV is 50.71. NPV are the same even if they shorten the term of work using any technique on this condition in defiance of the discount rate.

All		0	1	2	3	4	5	6	7	8	9	10	11	12	13	···	69	70	71
Design		0	1	2	3	4	5	6											
Construction								0	1	2	3	4	5						
Rental													0	1	2	···	58	59	60
Owner	Cache In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.43	···	1.43	1.43	76.43
	Cache Out	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	0.00	-30.00	0.00	-40.00	0.00	0.00	···	0.00	0.00	0.00
	Cache Flow	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	0.00	-30.00	0.00	-40.00	1.43	1.43	···	1.43	1.43	76.43
	Present Value	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	0.00	-30.00	0.00	-40.00	1.43	1.43	···	1.43	1.43	76.43
	Net Present Value	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	-40.00	-40.00	-70.00	-70.00	-110.00	-108.57	-107.14	···	-27.14	-25.71	50.71
Contractor	Cache In	0.00	0.00	0.00	0.00	0.00	0.00	40.00	0.00	0.00	30.00	0.00	40.00						
	Cache Out	0.00	-1.56	-1.56	-1.56	-1.56	-1.56	-1.56	-18.70	-18.70	-18.70	-18.70	-18.70						
	Cache Flow	0.00	-1.56	-1.56	-1.56	-1.56	-1.56	38.44	-18.70	-18.70	11.30	-18.70	21.30						
	Present Value	0.00	-1.56	-1.56	-1.56	-1.56	-1.56	38.44	-18.70	-18.70	11.30	-18.70	21.30						
	Net Present Value	0.00	-1.56	-3.12	-4.68	-6.23	-7.79	30.65	11.95	-6.75	4.55	-14.15	7.15						

Table 1: Worksheet of cash flow calculation (5-months term of work project)

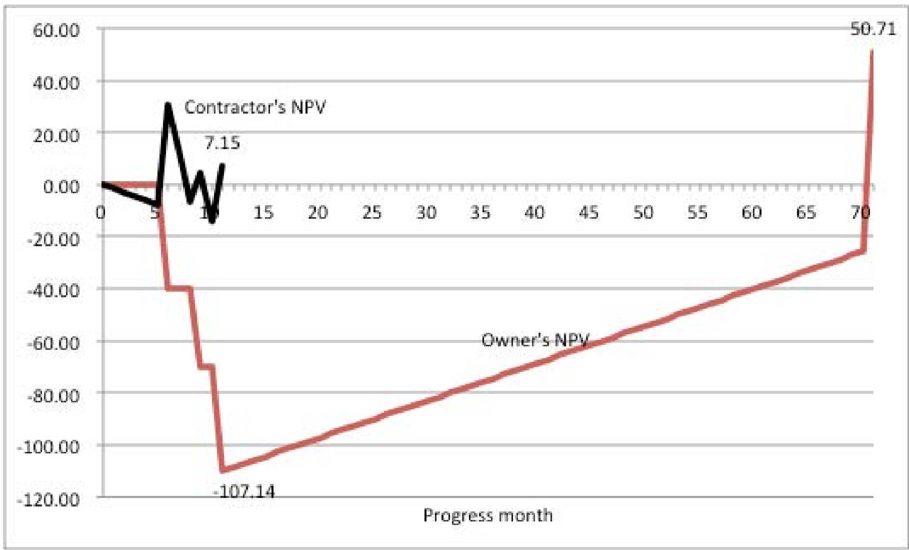


Figure 4: Change of NPV (5-months term of work project)

3.2. Present Value of the Discounted Cash Flow

DCF analysis yields the overall value of a business, including both cash out and cash in. DCF analysis is a technique determining what a business is worth today in light of its cash yields in the future.

Table 2 shows NPV discounted at 10% with all other conditions the same as Table 1. As for NPV of the contractor it falls from 7.15 to 6.55 and the owner one falls from 50.71 to 0.57. The influence of the discount rate strongly appears to the owner having a long rental stage.

All		0	1	2	3	4	5	6	7	8	9	10	11	12	13	···	69	70	71
Design		0	1	2	3	4	5	6											
Construction								0	1	2	3	4	5						
Rental													0	1	2	···	58	59	60
Owner	Cache In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.43	1.43	1.43	1.43	1.43	76.43
	Cache Out	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	0.00	-30.00	0.00	-40.00	0.00	0.00	0.00	0.00	0.00	0.00
	Cache Flow	0.00	0.00	0.00	0.00	0.00	0.00	-40.00	0.00	0.00	-30.00	0.00	-40.00	1.43	1.43	1.43	1.43	1.43	76.43
	Present Value	0.00	0.00	0.00	0.00	0.00	0.00	-38.06	0.00	0.00	-27.84	0.00	-36.51	1.29	1.28	0.81	0.81	0.80	42.40
	Net Present Value	0.00	0.00	0.00	0.00	0.00	0.00	-38.06	-38.06	-38.06	-65.90	-65.90	-102.41	-101.12	-99.83	-43.44	-42.63	-41.83	0.57
Contractor	Cache In	0.00	0.00	0.00	0.00	0.00	0.00	40.00	0.00	0.00	30.00	0.00	40.00						
	Cache Out	0.00	-1.56	-1.56	-1.56	-1.56	-1.56	-1.56	-18.70	-18.70	-18.70	-18.70	-18.70						
	Cache Flow	0.00	-1.56	-1.56	-1.56	-1.56	-1.56	38.44	-18.70	-18.70	11.30	-18.70	21.30						
	Present Value	0.00	-1.55	-1.53	-1.52	-1.51	-1.49	36.57	-17.64	-17.50	10.49	-17.21	19.44						
	Net Present Value	0.00	-1.55	-3.08	-4.60	-6.11	-7.60	28.97	11.33	-6.17	4.32	-12.89	6.55						

Table 2: Worksheet of discount cash flow calculation

Figure 6 shows the influence that the change of the discount rate of the cross axle given in NPV. The discount rate increases; NPV is shown to drop. The discount rate when net present value becomes zero comprises the Internal Rate of Return (IRR) of the project. In this setting, the success of a 20-months term of work project becomes severe or uncertain, because the IRR of the 20-months term of work project is bigger by 1.8% than that of the 5-months term of work project.

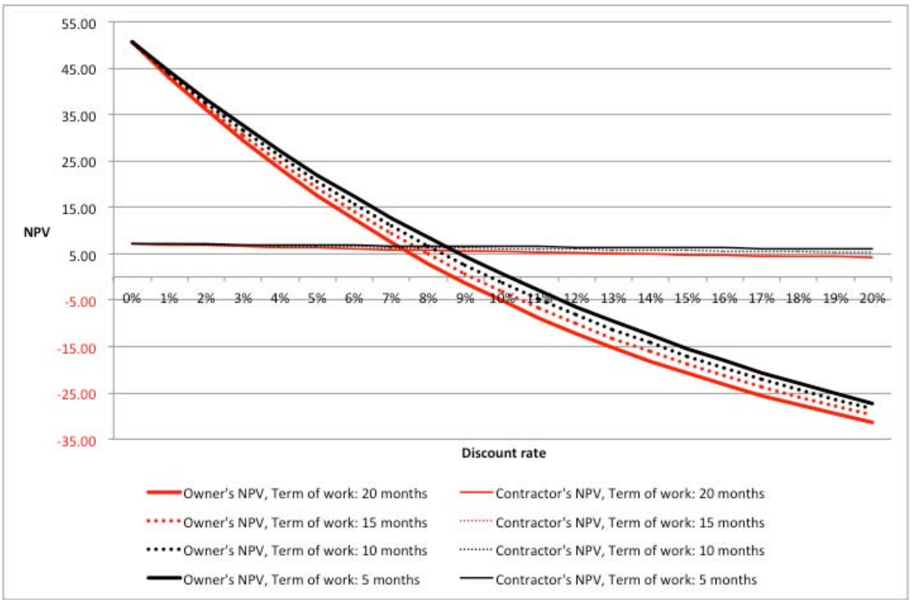


Figure 6: Change of NPV and IRR

Figure 7 shows that change of NPV when the term of work is assumed 5-months and 20-months and discount rate is 5% and 10% respectively. In the latter half of the project and the remaining value evaluation, cash in reduces under the influence of the discount rate, and NPV decreases, too.

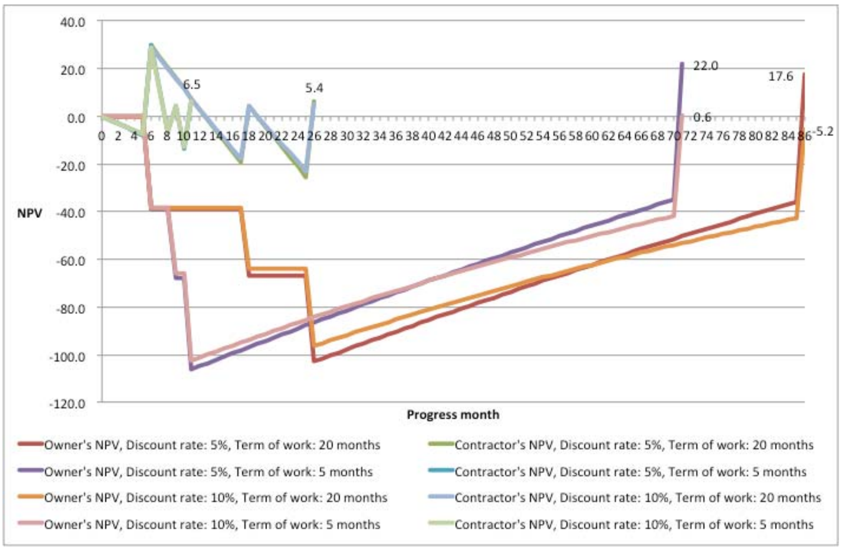


Figure 7: Change of NPV (5-months term of work and 20-months term of work and discount rate: 5% and 10%)

3.3. NPV of the DCF in Consideration of Ratio of Vacancy

In the simulations presented in sections 3.1 and 3.2, the occupancy rate of the apartment at 100 % is calculated in order to simplify the models. The occupancy rate is introduced in order to retrieve the risk of the project over the progress of the time. The authors use "Oracle Crystal Ball" which is the Excel-based application for the Monte Carlo model based simulation. The unevenness of the occupancy rate of this project is expressed in normal distribution (average: 95%, standard deviation: 15-30%). The standard deviation increases equally every month until the 86-months, from 15% to 30%. This setting expresses the actual situation in which the occupancy rate decreases by the progress of time. When the occupancy rate became higher than 100% in this simulation, it was regarded that both inhabitants and the rent rose.

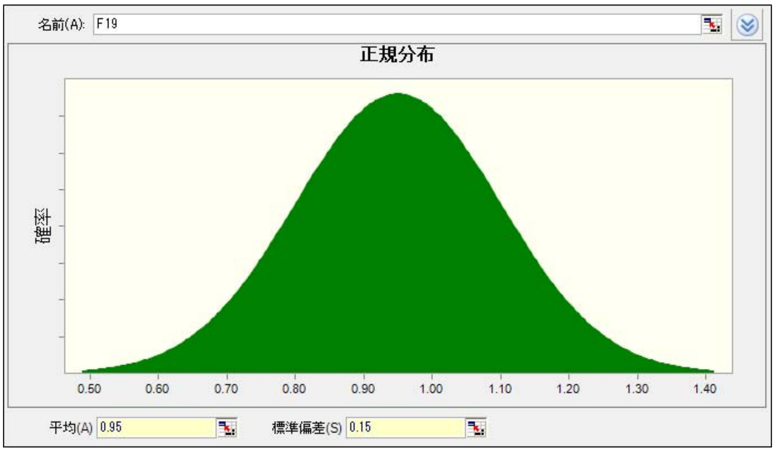


Figure 8: Example of the probability distribution of the occupancy rate (average of occupancy rate: 95% and standard deviation: 15%)

Figure 9 and 10 shows that owner's minimum and average NPV simulation results. It comprises a comparison of an extreme condition, i.e. the NPV of the 5-months term of work project exceeded the NPV of 20-months term of work project. In the case of 8% of discount cash flow, which are realistic in economic developing countries, NPV of 5-months term of work project can ignore the possibility to become smaller than 0 whereas 20-months term of work project has nearly 50% of possibility that NPV becomes smaller than 0.

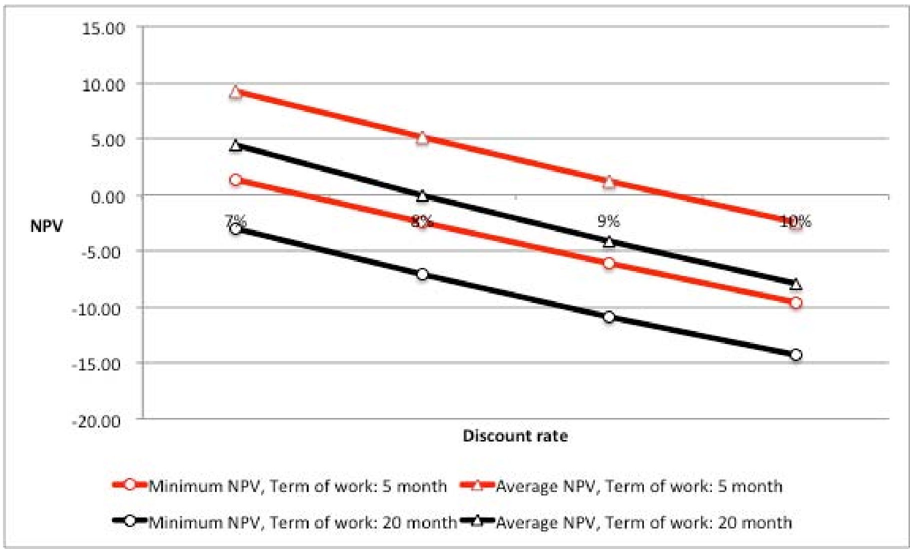


Figure9: Change of minimum and average owner's NPV

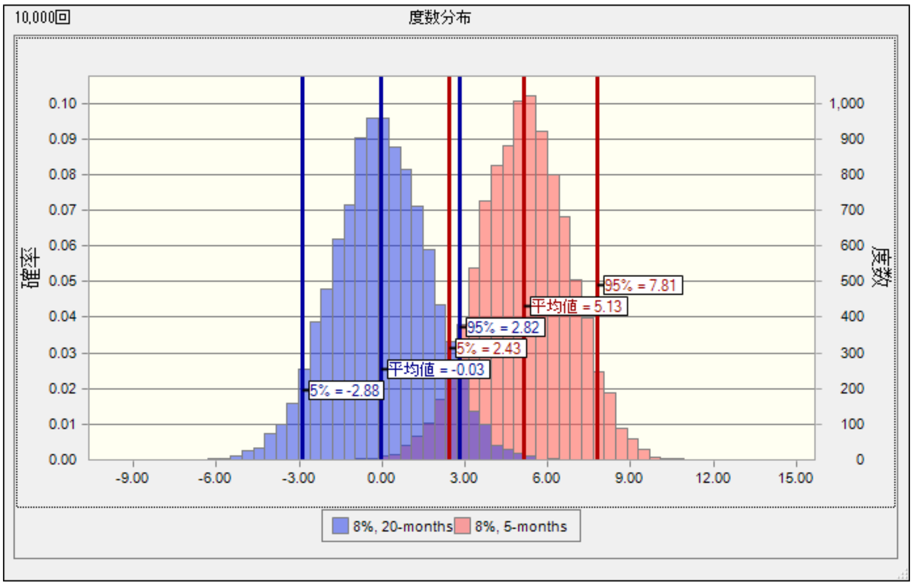


Figure10: Comparison of the prediction distribution of the owner's NPV (8%, 5-months term of work project and 8%, 20-months term of work project)

4. CONCLUSIONS

In this paper, we clarified the consequence that shortening the term of work by the introduction of innovative construction methods like automation and robotics increases the NPV of the project. Similarly, if the proposed cash flow model is introduced, which incorporates quality and safety improvement, the upper limit of the additional investment such as R&D costs for the realization can be extracted from the increase of NPV. It is not realistic to collect costs from single projects. The total investment for R&D should be decided assuming the total number of similar projects provided. Contractors should inform owners that involved innovative construction methods could eventually efficiently increase the NPV of a building. This leads to releasing contractors from price competition. The proposed study is important not only for contractors but also for owners.

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A STUDY OF GENERAL CONTRACTORS' MANAGEMENT STRATEGIES: A TIME SERIES ANALYSIS OF THE ENR TOP INTERNATIONAL CONTRACTORS 225

Kazuyoshi Endo
Kogakuin University, Tokyo, Japan, endo@sin.cc.kogakuin.ac.jp

Thomas Bock
Technische Universität München, Munich, Germany, thomas.bock@br2.ar.tum.de

Thomas Linner
Technische Universität München, Munich, Germany, thomas.linner@bri.arch.tu-muenchen.de

Jun Iwamatsu
Research Institute on Building Cost, Tokyo, Japan, iwamatsu@ribc.or.jp

Kepa Iturralde
Euskal Herriko Unibertsitatea, San Sebastián, Spain, kepaiturralde@coavn.org

Abstract

Today's construction market and industry are in a state of chaos throughout the world. The globalization of this market demands that national governments and construction contractors associations, as well as construction contractors, set in place effective strategies to overcome such turmoil. This paper examines the strategies used by major contractors. These contractors were selected from a series of international rankings, which was compiled and published by the U.S. based Engineering News Record. Starting with data from 2000, three trends were observed. Firstly, Chinese contractors stand out with strong performances. In the 2012 ranking, five out of the top 10 contractors were Chinese. Their growth is derived from China's high domestic demands. Secondly, while some American and European contractors have done well, others have not. Several firms increased their revenues and thus kept their top 10 statuses. The fates of European contractors seem to be related to how well they adjusted to the economic unification of the European Union. The last major trend is the disappearance of Japanese contractors, which used to always secure positions in the top 10 rankings until about 2005. Possible reasons for this change are: the drastic reduction of the Japanese domestic market due to an aging population with a declining birthrate, policy changes in public construction spending, and the contractors' delayed reactions to markets abroad. We analyze the management strategies used by major contractors and aim to speculate upon probable future trends.

Keywords: corporate strategy, general contractor, construction industry, construction market, engineering news record.

1. OVERVIEW OF THE STUDY

1.1. Background: The Rapidly Changing Global Construction Market

Today's construction market and industry are in a state of worldwide turmoil. The center of this global construction market is shifting rapidly from the U.S., Europe and Japan to China, South East Asia, the Middle East, Central Europe and Africa. Most notably, Japan's investment in the construction sector reached 84 trillion yen in 1992 and thus Japan became the world's largest construction market, surpassing those of the U.S. and the entire European Union (EU) at that time. However, with the burst of the Japanese bubble economy, the country's aging population with a declining birthrate, the reduction in public construction spending and the saturation of existing construction, Japan's investment declined to approximately 49% of its peak in 2010. The European and the American markets have also been struggling due to the global financial crisis, which began in the U.S. in 2007, and the European debt crisis, which started in 2009.

Figure 1 shows the changes in the size of various construction markets between 2008 and 2012, as well as their estimated size in 2013 (Ifo Institute, 2012). The countries shown in this figure contain the headquarters of the contractors that we selected for this study. While China's growth is outstanding, the world's major contractors continue to maintain their bases in their home countries where domestic markets are stagnated. New effective strategies must be set in place by these nations' public administrations, construction contractors associations and construction contractors so that they can adapt themselves to the changes in the construction market.

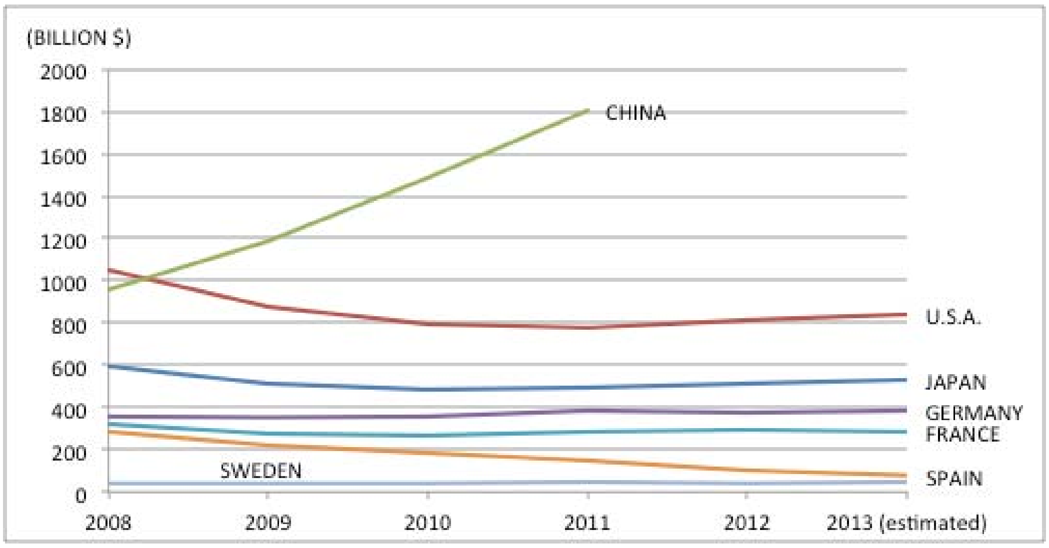

Figure1: Trends in Construction Spending

1.2. Objectives: Understanding the Strategies used by Successful Global Contractors

The aim of this study was to understand the strategies used by the world's major contractors in the above-described context. Such contractors were selected from a series of international revenue-based rankings, compiled and published by the U.S. based Engineering News Record (hereafter referred to as the ENR Top 225). Because American and European advances in overseas operations are particularly remarkable, we examined the performances of some American and European contractors with growing revenues. Then, we extracted some of these contractors' salient points, which seemed most relevant to what Japanese contractors should take into account in order to better equip themselves for the coming years.

1.3. Methods: A Time Series Analysis of the ENR Top 225

The ENR Top 225 contains two rankings. One is the ENR Top 225 International Contractors (hereafter referred to as the ENR Int'l Top 225), in which "companies are ranked according to construction revenue generated outside of each company's home country in U.S. $ millions" (ENR, 2012). The other ranking is the ENR Top 225 Global Contractors (hereafter referred to as the ENR Global Top 225), which ranks contractors according to their total revenue (in millions of U.S. dollars), i.e., from both inside and outside each contractor's home country. Each contractor's domestic revenue can be calculated by subtracting the revenue listed in the first ranking from that in the second. Both of these rankings are based on revenues from the previous year. In both of these ENR Top 225 rankings, contractors' total revenues are divided into the following 10 sectors and the revenue from each sector is shown as a percentage: general building, manufacturing, power, water supply, sewerage/solid waste, industrial process, petroleum, transportation, hazardous waste, telecommunications and others.

Using data from these two ENR Top 225 rankings over a period of 13 years (from 2000 to 2012), we analyzed the management strategies adopted by the selected contractors. More specifically, we studied the changes over time in each contractor's rankings, the ratio of their overseas operations and their distribution of work among the 10 sectors.

2. TRENDS AMONG THE MAJOR CONTRACTORS

2.1. Comparison of the 2000 and 2012 ENR Global Top 20 Rankings

To keep our analysis results simple, we extracted and compared the top 20 contractors from the ENR Global Top 225 in 2000 and 2012 (see Tables 1 and 2 respectively). We found the following three significant changes between these two rankings at the beginning and the end of the 13-year period:

Firstly, Chinese contractors stand out due to their strong performances. In the 2012 ranking, five out of the top 10 contractors were Chinese. Their growth is mostly due to China's high domestic demands, a phenomenon akin to that of Japanese contractors in 2000. The Chinese contractors' overseas activities are small in proportion to their overall operations, but they are not insignificant (in terms of monetary value) when compared to those of Japanese contractors in 2000. The main overseas destinations of the 52 Chinese contractors listed in the ENR Top 225 are Africa, Asia and the Middle East. Approximately 40% of the overall revenue earned by foreign contractors in Africa is attributed to the Chinese. This share exceeds that of all of the European contractors put together.

Secondly, while some American and European contractors have done well, others have not. Several contractors from the U.S., Germany, France and Spain increased their revenues and maintained their top 10 statuses. The fates of European contractors seem to be associated with how well they have adapted themselves to the economic unification of the EU. The introduction of the euro as a common currency, as well as the free movement of people, goods, capital and services within the EU, must have affected the European contractors during the years between 2000 and 2012. The GDP of the EU as a whole is around 2.5 times more than that of Japan, and it is comparable to that of the U.S. With respect to the construction market, the EU market was approximately four times larger than the Japanese market in 2008.

The last notable change is the disappearance of Japanese contractors, which used to always secure positions in the top 10 rankings until around 2005. The drastic reduction of the Japanese domestic market due to an ageing population with a declining birthrate, policy changes in pubic-sector construction spending and contractors' delayed reactions to the markets abroad are believed to be the main reasons for this deterioration. Prior to the Great East Japan Earthquake in March of 2011, the Japanese Ministry of Land, Infrastructure, Transport and Tourism used to urge large contractors to shift their focus abroad in order to resolve the problem of domestic supplier surplus in the construction industry. The market that these Japanese contractors have picked as their immediate target is the improvement of infrastructure in South East Asia. Because the European construction sector is also highly interested in this area, competition is expected to grow significantly fiercer in the coming years. In the meantime, the new need for reconstruction after the Great East Japan Earthquake and Japan's Liberal Democratic Party's take-over of political power in December of 2012 have brought many Japanese contractors' focuses back to the Japanese domestic civil construction sector. Therefore, the future of Japan's policies regarding the internationalization of its contractors and that of the Japanese construction sector's related strategies is not clear.

RANK	FIRM	NATIONALITY	REVENUE (MIL. $)	
			TOTAL	INT'L
1	TAISEI CORP.	Japan	13,909	681
2	SHIMIZU CORP.	Japan	12,261	760
3	KAJIMA CORP.	Japan	11,591	1,097
4	BOUYGUES	France	11,462	5,007
5	BECHTEL	U.S.A.	11,240	7,442

6	OBAYASHI CORP.	Japan	10,538	843
7	TAKENAKA CORP.	Japan	9,258	691
8	VINCI	France	9,098	3,600
9	FLUOR CORP.	U.S.A.	8,707	4,669
10	KVAERNER PLC GROUP	U.K.	8,420	6,540
11	KUMAGAI GUMI CO. LTD.	Japan	8,407	782
12	SKANSKA AB	Sweden	8,232	5,984
13	HOCHTIEF AG	Germany	7,833	4,402
14	GROUPA GTM	France	7,591	3,162
15	KELLOGG BROWN & ROOT (KBR)	U.S.A.	6,399	4,721
16	TODA CORP.	Japan	5,680	89
17	EIFFAGE	France	5,645	708
18	BOVIS LEND LEASE	U.K.	5,341	4,113
19	NISHIMATSU CONSTRUCTION CO. LTD.	Japan	5,209	721
20	KINDEN CORP.	Japan	4,934	174

Table 1: 2000's Top 20 Contractors in the ENR Global Top 225 (in millions of U.S. dollars)

RANK	FIRM	NATIONALITY	REVENUE (MIL. $)	
			TOTAL	INT'L
1	CHINA RAILWAY GROUP LTD.	China	79,852	2,827
2	CHINA RAILWAY CONSTRUCTION CORP. LTD.	China	77,947	3,782
3	CHINA STATE CONSTRUCTION ENG'G CORP. LTD.	China	68,326	4,510
4	VINCI	France	52,404	18,674
5	CHINA COMMUNICATIONS CONSTRUCTION GROUP LTD.	China	46,007	9,547
6	GRUPO ACS	Spain	42,083	31,148
7	HOCHTIEF AG	Germany	33,775	31,871
8	BOUYGUES	France	31,656	12,608
9	CHINA METALLURGICAL GROUP CORP.	China	31,529	2,623
10	BECHTEL	U.S.A.	25,005	16,700
11	LEIGHTON HOLDINGS LTD.	Australia	21,203	3,921
12	STRABAG SE	Austria	20,071	17,289
13	FLUOR CORP.	U.S.A.	18,685	13,527
14	SINOHYDRO GROUP LTD.	China	18,086	4,400
15	KAJIMA CORP.	Japan	16,790	2,456
16	SHANGHAI CONSTRUCTION GROUP	China	16,683	1,110
17	FCC, FOMENTO DE CONSTR. Y CONTRATAS SA	Spain	16,344	8,570
18	SKANSKA AB	Sweden	16,233	12,339
19	OBAYASHI CORP.	Japan	15,567	2,077
20	SHIMIZU CORP.	Japan	14,876	1,227

Table 2: 2012's Top 20 Contractors in the ENR Global Top 225 (in millions of U.S. dollars)

2.2. Changes Over Time in the Gross Sales of 17 Contractors

Keeping in mind this study's objectives, we selected the following 17 contractors from Tables 1 and 2 for analysis:

– Bechtel and Fluor Corporation, two American contractors that are in the top 20 in both years' rankings; Bouygues and Vinci, two French contractors that are in the top 10 in both years; and Hochtief AG from Germany

– Grupo ACS, a Spanish contractor that grew rapidly and entered the top 10 in 2012

– Five from China: China Communications Construction Group Ltd., China Metallurgical Group Corporation, China Railway Construction Corporation Ltd., China Railway Group Ltd. and China State Construction Eng'g Corporation Ltd.

– Five large contractors from Japan: Kajima Corporation, Obayashi Corporation, Shimizu Corporation, Taisei Corporation and Takenaka Corporation

– Skanska AB from Sweden, which was included the top 10 ranking seven times over the 13-year period (though it was not included in the top 10 in 2000 or 2012). Despite the fact that this contractor is similar in size to the top Japanese contractors, its overseas business accounts for a higher share of its overall operations than those of its Japanese counterparts.

Figure 2 shows the changes in the total revenues of these 17 contractors over time. The Chinese contractors surpassed the Japanese around 2005, and outperformed the growing European contractors in 2009 when they stagnated due to the European debt crisis. Regardless of the global economic turmoil, China's investment in construction continued to grow with the aim to achieve a minimum standard of living in its urban societies. The two American contractors grew rather more moderately than the Europeans, but their performances also deteriorated when the global financial crisis sprang up in their own country. The Japanese contractors also showed moderate growth up to 2009, as that period coincided with Japan's second-generation baby boomers' house purchases. However, the performance of the Japanese contractors took a down swing in 2009 with the wake of the global financial crisis. Reconstruction projects after the Great East Japan Earthquake are the reason for the Japanese contractors' slight recovery in 2011. The Swedish contractor Skanska AB shows a trend similar to that of the Japanese contractors.

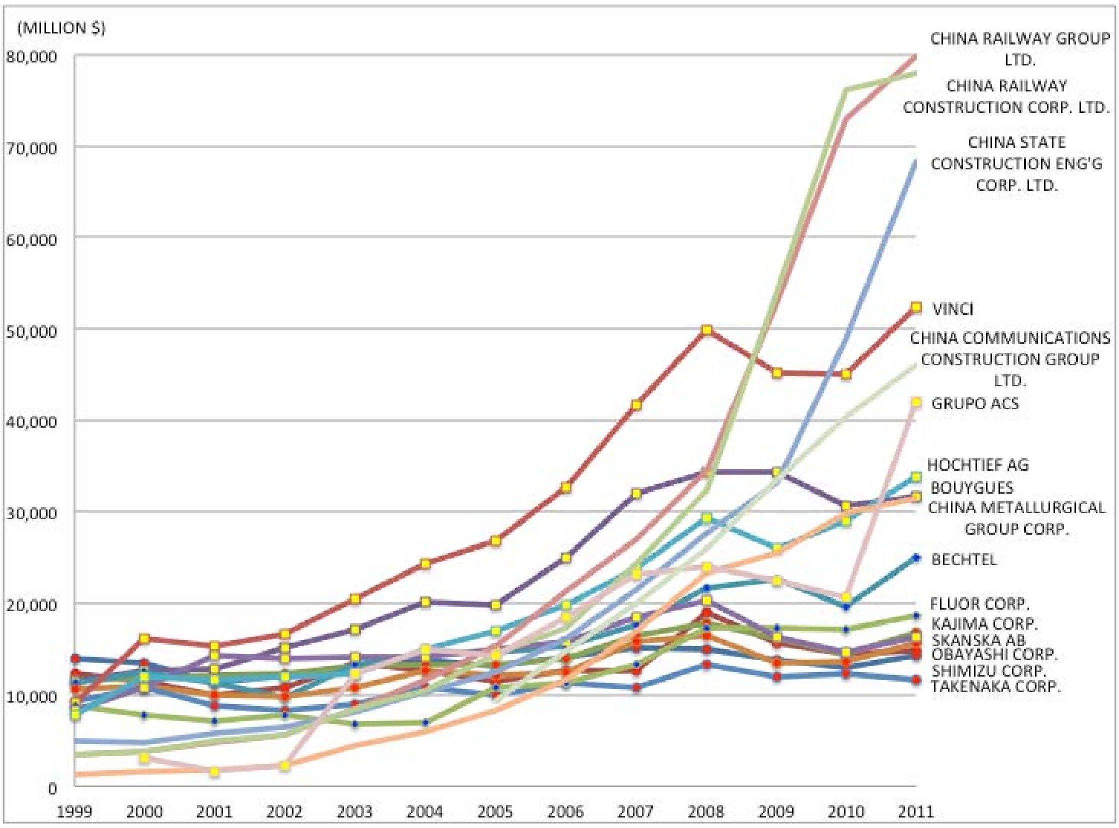

Figure 2: Changes Over Time in the 17 Contractors' Gross Sales (shown by their company names in 2012)

While Figure 2 shows the 17 contractors' total revenues in U.S. dollars, we must take into consideration currency exchange rates in order to more accurately study the performance of the Japanese contractors. Figure 3 compares the total revenue of the Taisei Corporation, the top Japanese firm in the ENR ranking of 2000, in yen and dollars. (The yen values come directly from Taisei's securities reports, and the dollar values directly from the ENR Top 225.) Using this company's revenue in 2002 as the baseline, i.e. 100%, its revenue in the two currencies are compared over time. The Japanese contractors drew 90% of their total revenues from domestic operations. Taisei's revenue in yen shows a more significant drop than its revenue shown in dollars.

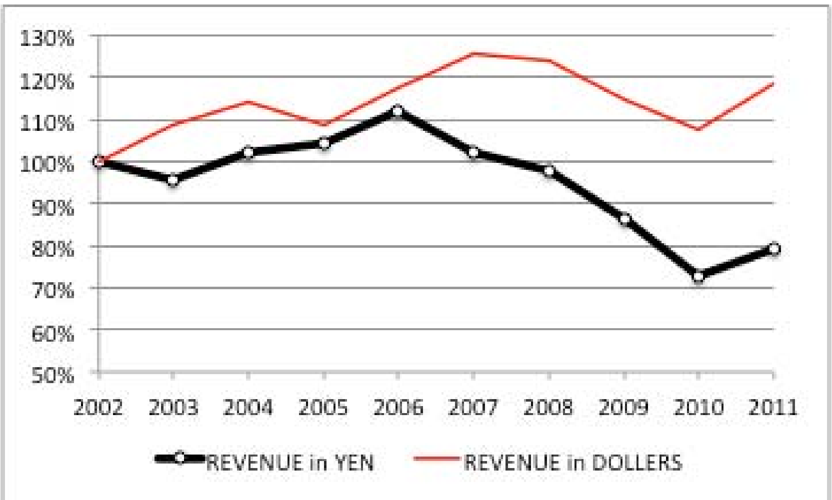

Figure 3: Changes Over Time in Taisei Corporation's Revenue in Yen (Security report) and in U.S. Dollars (ENR data), using its revenue from 2002 as the baseline

3. ANALYSIS OF THE MAIN TOPICS OF INTEREST

Based on the data from the 17 contractors, we extracted three topics of interest, which we will analyze in the following sub-sections.

3.1. The Strategies Used by Grupo ACS and Hochtief AG, the Two Growing EU Contractors

Grupo ACS grew due to its domestic earnings in Spain until the onset of the global financial crisis. In 2007, this company's overseas work accounted for only 16% of its overall operations. Since then, however, the Spanish domestic market has shrunk radically (see Figure 1), and so did Grupo ACS's revenue in 2009 and 2010. Nevertheless, this company drastically increased the share of its overseas operations in 2011 and thus grew significantly in total revenue. In that same year, Grupo ACS acquired the majority of Hochtief AG's stock through a tender offer. (As mentioned earlier, Hochtief AG is a growing German contractor.) Despite the fact that Grupo ACS is a young company that was founded in 1997, it has been actively expanding its operations through business acquisitions from its start. Currently, this company operates as a corporate group of 10 companies in the areas of construction, environmental business, concession business and energy, and has approximately 140,000 employees worldwide. Hochtief AG and Grupo ACS were ranked first and second on 2012's ENR Top Int'l 225 in the regional categories of Asia and the U.S. Grupo ACS also claimed a large share of the Spanish-speaking Latin American construction market.

3.2. The Relationship Between the Reduction of Domestic Markets and the Shifting of the Contractors' Focuses to Overseas Operations

Figure 4 shows the changes in the ratios of the 17 contractors' overseas operations over time. How each country handles its overseas advances is apparent. The Chinese and Japanese contractors have low ratios of overseas operations, while the French maintain their ratios at around 40%. The Americans, on the other hand, have raised the percentages of their overseas work over the 13-year period.

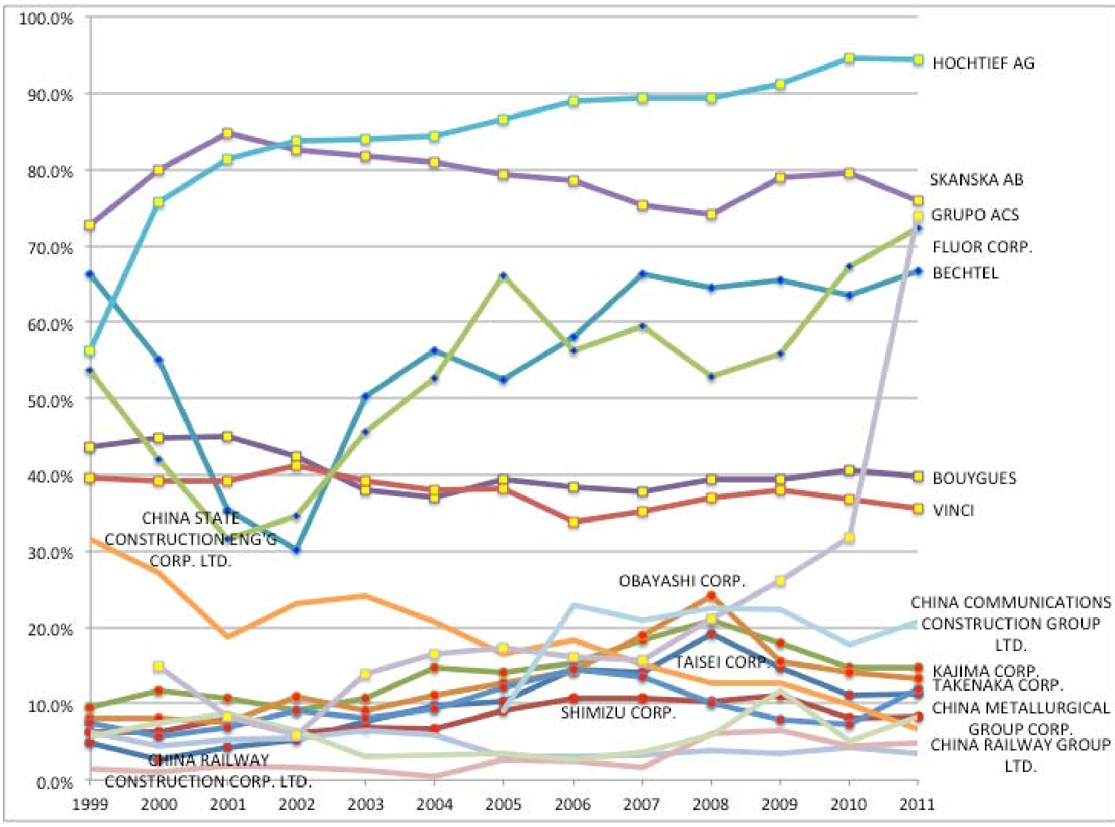

Figure4: Changes Over Time in the 17 Contractors' Ratios of Overseas Operations (shown by their company names in 2012)

Until now, Japanese overseas advances have served to compensate for drops in domestic demands, which almost always have been high. Japanese contractors' aim was to allocate their excess labor abroad. Their advances in the Middle East after the 1970s energy crisis and in South East Asia in the first half of the 1980s are typical examples. The contractors that made these advances never fully developed their foreign operations, because they expected Japan's domestic market to recover quickly. Although these large contractors still have branch offices and affiliated local companies there, they mostly operate on a project-to-project basis by sending small numbers of managers from Japan to oversee the construction of local facilities for Japanese client firms that are expanding their businesses in those regions. Recently, Japan's Abe Administration decided to move forward with its intention to join the

Trans-Pacific Partnership (TPP). We wait with keen interest to see how Japanese contractors will react to this new development.

Hochtief AG and Skanska AB have consistently maintained high ratios of overseas operations over the 13 years. Skanska AB has had operations in 50 countries during the same period, and its ratio of overseas activities has been stable at around 80%. This contractor has two goals to achieve whenever they enter a foreign market. One is to become one of the top three construction contractors in that market. The second is to have a local base in every country where they have operations. These goals served as a driving force for this company to acquire businesses in Europe and the U.S. and to grow in revenue between 1998 and 2000. However, Skanska AB's revenue has not grown since the onset of the global financial crisis (see Figure 2). It will be interesting to observe how this company will maneuver to gain a foothold in newly developing markets that are replacing the U.S. and Europe.

3.3. Differences Between a Contractor's Strong and Weak Sectors, in Both Domestic and Overseas Markets

Table 3 shows the by-sector components of the gross sales and the overseas sales of 12 contractors. The 12 companies are the result of eliminating the Chinese contractors from the 17 selected contractors. Each company's gross sales and their by-sector components were compared with their overseas sales, and the differences calculated. Cells with absolute values greater than 10 are marked with bold borders. We found that the European and American contractors with high ratios of overseas operations have similar distributions of revenue among the 10 sectors in their overseas and gross sales. In other words, these contractors are strong in the same sectors both domestically and abroad. In contrast, the Japanese contractors have smaller ratios of overseas revenue generated from building projects than they do overall. Instead, high proportions of their overseas sales come from civil engineering and infrastructure projects. In other words, the Japanese are using a strategy of reutilization abroad; they take advantage of technologies that have already been employed in Japan for their overseas projects. Such technologies include long span bridges, undersea tunnels, water and sewerage treatment and bullet trains.

FIRM	REVENUE $ MIL.			GEN. BLDG.	MFG.	POWER	WATER SUPPLY	SEWER/WASTE	INDUS./PETRO.	TRANSP.	HAZ.WASTE	TELECOM	OTHER
HOCHTIEF AG	INT'L	31871	(A)	30	2	2	7	3	6	24	0	5	21
	TOTAL	33775	(B)	32	1	2	7	3	5	24	0	5	21
			(A) - (B)	-2	1	0	0	0	1	0	0	0	0
GRUPO ACS	INT'L	31148	(A)	25	1	13	6	3	5	26	0	4	17
	TOTAL	42083	(B)	22	1	14	6	6	6	29	0	3	13
			(A) - (B)	3	0	-1	0	-3	-1	-3	0	1	4
VINCI	INT'L	18674	(A)	13	0	12	2	0	8	51	1	5	8
	TOTAL	52404	(B)	16	0	12	2	0	4	39	1	5	21
			(A) - (B)	-3	0	0	0	0	4	12	0	0	-13
BECHTEL	INT'L	16700	(A)	0	0	0	0	0	70	30	0	0	0
	TOTAL	25005	(B)	0	0	17	0	0	54	22	5	2	0
			(A) - (B)	0	0	-17	0	0	16	8	-5	-2	0
BOUYGUES	INT'L	12608	(A)	29	0	3	1	1	2	60	1	0	3
	TOTAL	31656	(B)	38	0	5	1	1	3	49	0	1	2
			(A) - (B)	-9	0	-2	0	0	-1	11	1	-1	1
SKANSKA AB	INT'L	12339	(A)	47	3	2	3	3	5	31	0	3	3
	TOTAL	16233	(B)	53	2	2	3	2	4	29	0	3	2
			(A) - (B)	-6	1	0	0	1	1	2	0	0	1
KAJIMA CORP.	INT'L	2456	(A)	50	22	2	0	1	2	20	0	3	0
	TOTAL	16790	(B)	54	13	4	2	2	3	12	0	1	9
			(A) - (B)	-4	9	-2	-2	-1	-1	8	0	2	-9
OBAYASHI CORP.	INT'L	2077	(A)	38	10	4	12	2	0	30	0	2	2
	TOTAL	15567	(B)	59	8	3	3	1	7	15	0	2	2
			(A) - (B)	-21	2	1	9	1	-7	15	0	0	0
TAISEI CORP.	INT'L	1597	(A)	2	4	0	1	0	0	79	0	0	14
	TOTAL	14259	(B)	55	12	1	1	1	0	25	0	0	5
			(A) - (B)	-53	-8	-1	0	-1	0	54	0	0	9
TAKENAKA CORP.	INT'L	1397	(A)	11	48	0	0	36	0	0	0	0	5
	TOTAL	11675	(B)	77	15	0	0	5	0	0	0	0	3
			(A) - (B)	-66	33	0	0	31	0	0	0	0	2
SHIMIZU CORP.	INT'L	1227	(A)	36	29	9	3	0	18	4	0	0	1
	TOTAL	14876	(B)	56	9	3	2	1	9	8	1	4	7
			(A) - (B)	-20	20	6	1	-1	9	-4	-1	-4	-6
FLUOR CORP.	INT'L	13527	(A)	16	1	3	0	0	75	5	0	1	0
	TOTAL	18685	(B)	13	1	5	0	0	65	10	4	2	0
			(A) - (B)	3	0	-2	0	0	10	-5	-4	-1	0

Table 3: Comparison of the By-Sector Ratios of the Major European, American and Japanese Contractors' Gross and Overseas Sales

4. CONCLUSIONS: RECOMMENDATIONS FOR JAPANESE CONTRACTORS

The reduction of Japan's construction market is an inevitable consequence of the country's economic and social maturity. In the coming years, Japanese contractors must use strategies that are based on that reality. They must gear themselves towards new markets: the reconstruction needs in the Japanese domestic market due to an aging population and a declining birthdate and overseas operations. This study mainly focused on the latter market, i.e. overseas. Below, we summarize the actions that we believe are necessary for Japanese contractors to succeed in foreign markets.

Japanese contractors depend highly on multi-layered subcontractors for on-site work in the domestic market. They base their project management on the close ties that they establish with their subcontractors. Thus far, they have applied the concept of "nurturing" similar production systems in their overseas operations. However, in order to adapt themselves quickly to the rapid changes in the market, Japanese contractors should consider the possibility of acquiring overseas businesses, as in the case of Grupo ACS and Hochtief AG. In the manufacturing industry, for instance, it is not unusual for foreign contractors to acquire local enterprises to facilitate their operations in new locations, as well as to merge and acquire businesses to develop new markets there. At the same time, it is important for

Japanese contractors to study the mechanisms that European contractors use to manage their corporate groups from their home headquarters while they expand their businesses through mergers and acquisitions internationally.

Some EU countries have regulations to limit the subcontracting of labor to one tier, thus forcing contractors to employ skilled workers directly. In the construction sector, where the amount of work fluctuates greatly, the direct employment of such workers is a burden on the contractors. However, EU contractors seem to reduce the impact of this burden by increasing their workers' on-site productivity. Japanese contractors must learn from such management strategies.

Lastly, we found that the top Japanese contractors are strong in different sectors overseas than in the Japanese domestic market. At present, their strengths abroad correspond to the areas that have already been thoroughly researched and implemented in Japan. In order to keep their strong footholds abroad, Japanese contractors must set in place mechanisms for research, development and implementation that are especially geared toward foreign markets.

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BEHAVIOR CHARACTERISTIC OF DEPLOYABLE DOMES IN CABLE-TENSIONED SCST STRUCTURES

Jang-Sub Eom
Changshin University, Changwon, Korea, eum@csc.ac.kr

Jin-Woo Kim
Gyeongsang National University, Tongyeong, Korea, kim@gnu.ac.kr

Abstract

From the past several decades, for developing creative construction techniques in special field conditions, extensive research has been carried out on the shape formation of space structures by means of self-erection. This paper is concerned with the form finding of cable-tensioned SCST structures. The experimental models are consisted of deployable unit, from the planar structures on the ground, the space structures are shaped and erected into its final desired space structures by means of cable-tensioning. For the dome shape space structure models, the feasibility and the reliability of the proposed cable-tensioning techniques were confirmed with nonlinear finite element analysis and experiments. Through the experiments for the dome shaped space structures by means of cable-tensioning, it is shown that the proposed cable-tensioning technique could be applied the form finding of the SCST structures, so we can know the behavior characteristic and importance of the shape types for predicting in each models. For a special site condition of construction field, this cable-tensioning technique for SCST structure should be assumed an economical, fast, innovative, and reasonable construction method compare to the conventional construction method including the heavy crane and scaffold.

Keywords: cable-tensioning, dome shape, nonlinear finite element, shaping formation, SCST.

1. INTRODUCTION

Although the post-tensioning method has been used principally in concrete structures, its application to steel structures has gained acceptance in nowadays. The main advantage of cable-tensioned and shaped space structures is their fast and economical construction and fabrication in special construction site. In order to develop more innovative construction techniques, extensive research has been carried out on the shaping formation for space structures by means of cable-tensioning method. For instance, it has been used to build arch, barrel vault, dome, hypar shaped or planar frame steel structures as a shape formation and erection method. By investigating for cable-tensioning with theoretical analysis and experiments for the various models, the planar space trusses can be formed to a space shape and erected to the desired shape, if the mechanism and geometric compatibility conditions between the initial and final configurations are satisfied simultaneously. The main advantage of cable-tensioned and shaped space structures over conventional space structures is its economy in construction. The purpose of this study is to investigate that a circular planar layout can be formed into a dome shaped space structures by cable-tensioning on the planar layout. And the advanced space structure is suggested with model test and analysis by improving the cable-tensioning process. Attention is paid to the essential aspects that lead to shape formation and self-erection, the initial planar layout, the space shape, the shape of attachment device for reducing the eccentricity of cable, and replacement of special members for preventing the loss of cable-tensioning force. Two models of such a cable-tensioned and shaped space domes are used to verify these ideas, the feasibility of the proposed shape formation method is demonstrated by theoretical analysis and test for experimental model A and B.

2. SHAPE FORMATION PRINCIPLE OF SCST STRUCTURES

As following the concept of cable-tensioning method in Fig. 1, before cable-tensioning, though the gap amount is none zero, after cable-tensioning, the structure is deformed with desired shape with closing the gap. The shape formation principle of cable-tensioned and shaped dome described is based on the mechanism condition and geometric compatibility condition. For a cable-tensioned and shaped space structures, a mechanism condition means that a mechanism or near mechanism condition (flexure only the top chords) must exist in its initial configuration, and that no mechanisms are allowed to exist in its final configuration. The mechanism condition of a cable-tensioned and shaped space structures in three-dimensional space can be expressed by a general Maxwell's criterion.

$R - S + M = 0$; where $R = 6 - (3j - r)$

Where, R = degree of static indeterminacy; S = number of independent pre-stress states that exist; M = number of independent mechanisms; b = total number of members; j = total number of joints; and r = number of restraints on the structure. Using this criterion, a mechanism condition of a cable-tensioned and shaped dome structures can be expressed as: $M \rangle 0$ ($R \langle 0$, $S=0$) in its initial planar layout, and $M=0$ ($R \geq 0$, $S \geq 0$) in its final space shape. An ideal geometric compatibility condition between the initial and final configuration of a cable-tensioned and shaped space truss is that all the non-gap members remain the same length (only deflection without large strain) during the shape formation process. Also, the distances between the joints in which the shorter bottom chords are placed to create gaps, must shorten to allow the cable-tensioning operation. The geometric compatibility condition of a cable-tensioned and shaped space structures can be described by means of the geometric models that reflect the relationship between the planar layout and the final space shape. The suitable basic structural type of the cable tensioned and shaped space structure is single-chorded space truss, it is called SCST structure. In the initial planar configuration for cable-tensioning, it is the SCST condition, so it has the mechanisms or near mechanisms. For these reasons, SCST can be shaped easily with relatively small cable-tensioning force. Because the SCST structure is very weak structure type, it can resist for deformation with only its weight, the friction of its joints, and flexural stiffness of the top chords. But after the cable-tensioning and the self-locking process, the SCST can be a stable structure. Though the cable-tensioning process may reduce the load resisting capacity, due to the existence of compressive pre-stress force in some critical members after shape formation, the reduction in ultimate load capacity of cable-tensioned and shaped space structure could be improved by stiffening only a few critical members decided by analysis. And although the top chords are flexed during the cable-tensioning, this bending is not serious for the safety of the structural behavior.

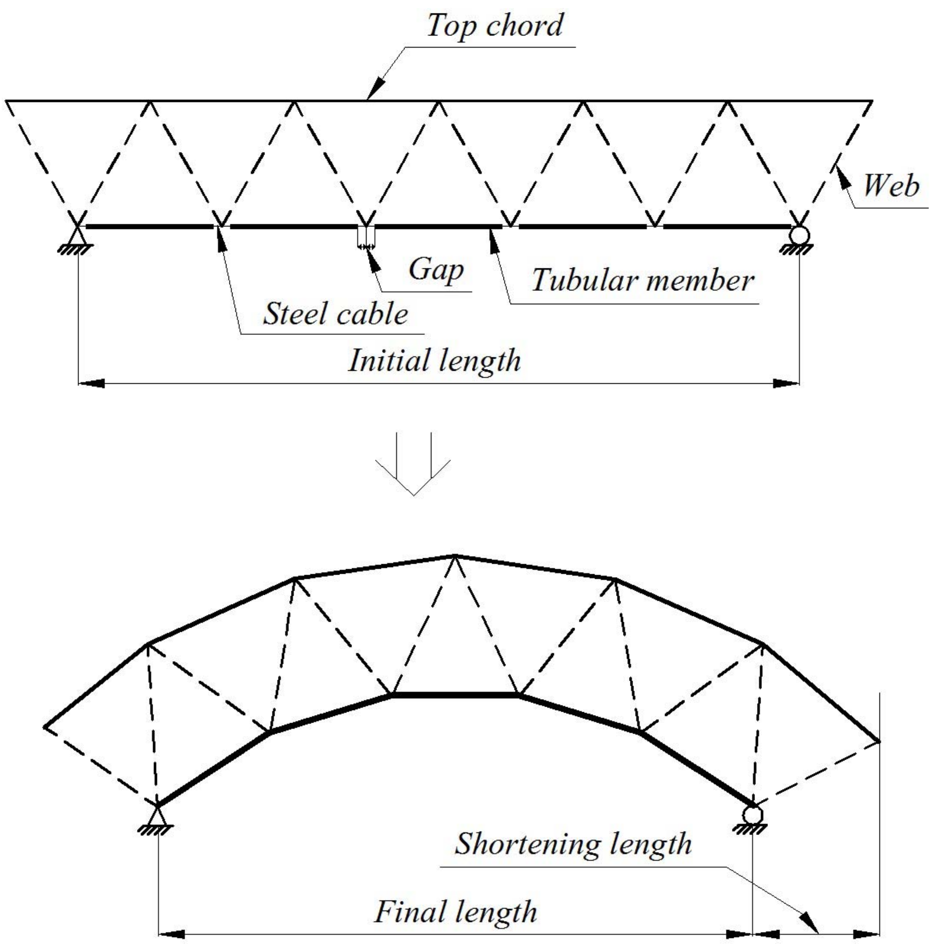


Figure 1: The Concept of Cable-tensioning Method in SCST Structure

3. FORMING FINDING AND ANALYSIS FOR EXPERIMENTAL MODELS

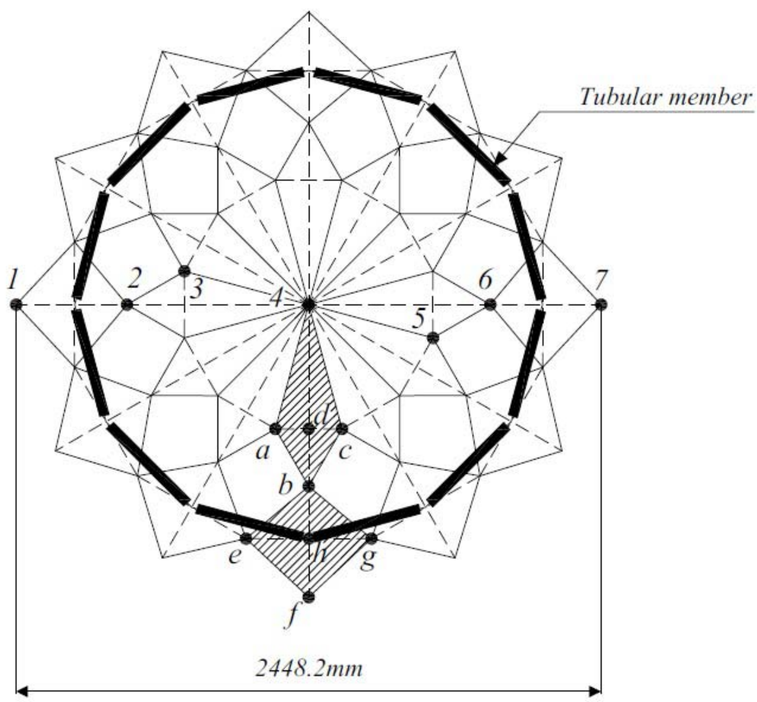
The basic requirement for the cable-tensioning method is that with relatively small cable-tensioning forces, the SCST can be formed and erected into the desired shape formation.

The cable-tensioning method for the dome shaped space structures can be investigated by experiments and nonlinear finite element analysis. The gap closing is given in proportion to the desired final shape from the finite-element analysis results. As the gap closing is completed, the structure is shaped into a curved configuration and erected into its final position. Basically these models are a kind of deployable types, they can be used with expandable structures according to their size. In these models, the hatched part is the basic unit structure, test models are constructed with connecting the basic unit structures. For model A, B, the properties of each member and geometry of the planar layouts are shown in Table 1 and Figure 2. In Figure 2 (a), the top chords (namely, 4a, ab, bc, 4c, be, ef, fg, bg) are noted with a thick line, and the web members (namely, 4d, ad, bd, cd, bh, eh, fh, gh) are noted with a thin dotted line. The cable for tensioning is located in the tubular member along the circumference connected with bottom joint. In Figure 2 (b), the top chords (namely, ab, bc, cd, de, bg, gh, ch) are noted with a thick line, and the web members (namely, aj, ej, af, bf, cf, df, ef, bi, gi, hi, ci) are noted with a thin dotted line. Without the tubular member, the cable for tensioning is located along the circumference connected with bottom joint, it is noted with bold dotted line. And it will be removed after cable-tensioning, it is replaced with new bottom chords as shown in Photo 1 (d). The planar layouts for model were assembled on the floor, one series of continuous chords were bolted together to form meshes of space structures. The web members were welded to a bottom joint, each member was bolted to the top chords stiffened with gusset plates. The depth of model A is 250mm, the depth of model B is 350 mm. Specially the central joint in this test model A is made of circular plate which is connected with all top chords and web members, it has large stiffness compare to any other joints. In general, because the joints of space structures are sensitive to stress and strain, therefore the characteristic of these joints effect to total behavior of space structure, and so on, it should be careful in design and construction for joints. In this point of view, the circular plate of central joint (node 4) in model A is replaced with octagon shaped grid in model B as shown in figure 2. Specially, in the model B, for preventing the loss of cable-tensioning force, after cable-tensioning, special member is replaced as a bottom chords, after that the cable is removed. As shown in Photo 1 (c), in the case of model B, without the tubular member, cable-tensioning force is applied, and shaping formation is progressed. The new devices are a function for reducing the eccentricity of the cable and bottom joints, and the device adopted roller to guide the cable, it is very effective device to decrease the friction between the cable and the attachment device. For most systems cable-tensioning, when a cable is tensioned to its full value, the jack is released and the pre stress is transferred to the anchorage. The anchorage fixtures that are subject to stresses at this transfer will tender deform, thus allowing the tendon to slacken slightly. Friction wedges employed to hold the wires slip a little distance before the wires can be firmly gripped. Though the amount for slippage depends on the type of wedge and the stress in the wires, it is known that an average value is around 0.1 inch. So during the usage public, as shown in Photo 1 (d), for preventing the loss of cable-tensioning force, new members were supplied.

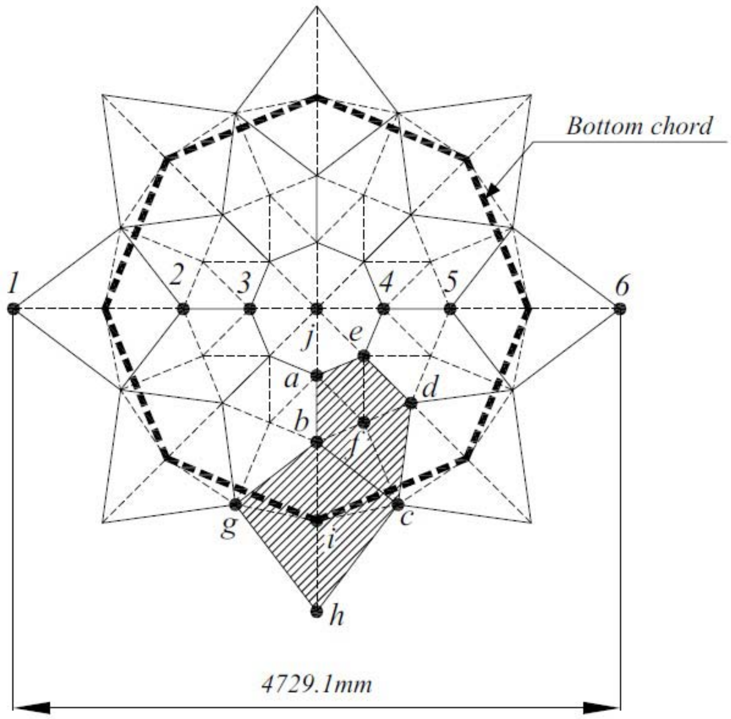
Table: Mechanical Properties of each Member

	Model A	Model B
Top Chord	SHS 13×13×1.5 mm	Member gh, hc : SHS 15×15×2.0 mm Member ab, bc, cd, de, ae : SHS 13×13×1.6 mm
Web Chord	CHS 13×2.5 mm	CHS 13×2 mm
Bottom Chord	CHS 13×2.5 mm	SHS 13×13×1.6 mm
Cable Area	24.6 mm^2	24.6 mm^2
Poisson' s Ratio(ɣ)	0.3	0.3
Yield Stress (σy)	Top Chord: 450 MPa Web Chord: 440 MPa Bottom Chord: 440 MPa Cable: 935 MPa	Top Chord: 350 MPa Web Chord: 350 MPa Bottom Chord: 350 MPa Cable: 935 MPa
Young's Modulus (E)	200,000 MPa	200,000 MPa

The dome shaped space structures are formed by cable-tensioning were shown in Photo 2. The cable-tensioning procedure began with the planar layout in its initial position, i.e. all the top chords were flat. A hand-operated hydraulic jack was used to apply a cable-tensioning force to the cable, and consequently, required curvature of the top chords is obtained by closing the gaps in the bottom. The cable-tensioning process was performed until all the gaps were closed, all the gaps were firmly closed, i.e. the tubular members of the bottom chords were completely locked into the bottom joint, the shaping formation is finished. In these procedures, the cable-tensioning forces applied in these models are small comparatively because of the characteristics for SCST.

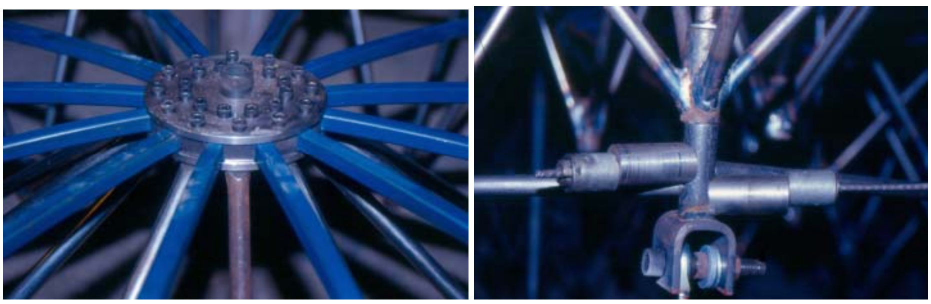


(a) Model A

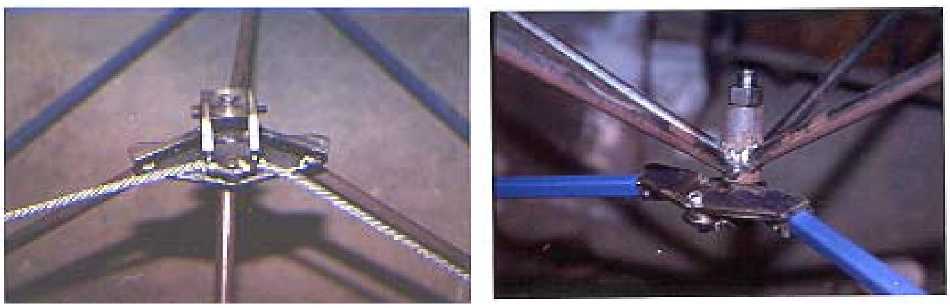


(b) Model B

Figure 2: Layouts of Models for Cable-tensioning



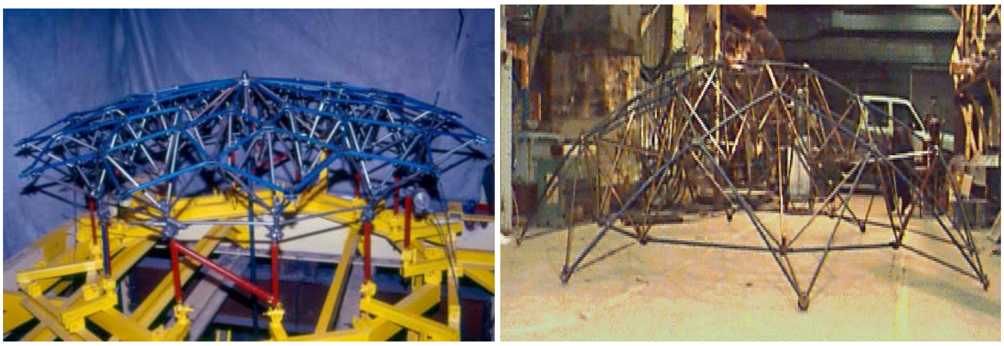
(*a) Top Plate of Model A (b)Cable Anchorage of Model A*



(c) Cable-tensioning of Model B (d) Replaced Special Member in Model B

Photo 1: Detailed Devices for Cable-tensioning in Models

For the nonlinear finite element analysis, the shortenings of the each bottom chords were simulated with a uniform negative temperature change at the bottom chords. For simulating the closing of the gaps during the shape formation process, the negative thermal load applied to the bottom chord. The finite-element analysis not only predicts the space shape, but also gives the cable-tensioning forces and the values of any induced stresses in each member, so the feasibility of a proposed cable-tensioning method can be confirmed. In nonlinear finite element analysis for experimental models, to consider the large displacement effects, an approximate updated Lagrangian method is employed. So the MSC/NASTRAN is used to consider the large displacement effects in the nonlinearity of the structure behavior. Based on the results of the finite-element analysis, the coordinates of every joint of the dome shaped space structures can be obtained. With these results, cutting the tubular members according to the values of the gaps, and assembling them in the planar layout, the structure can be formed to the desired space shape with the predicted cable-tensioning forces.

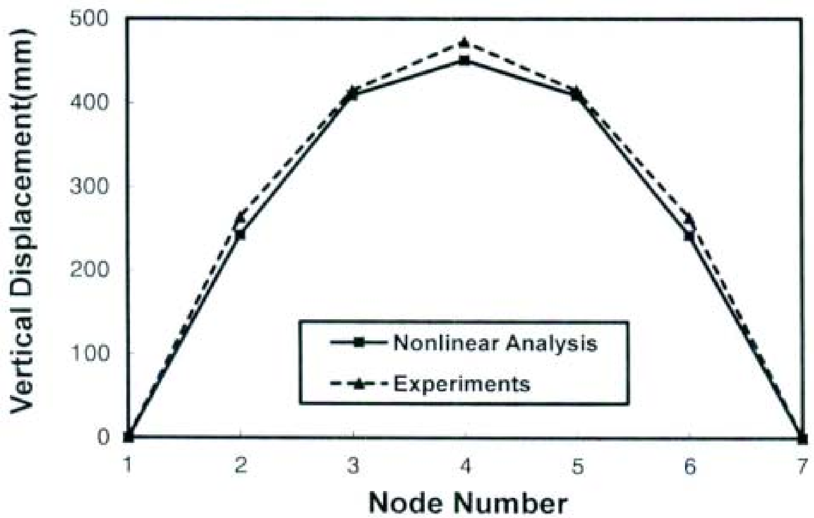


(a) Model A *(b) Model B*

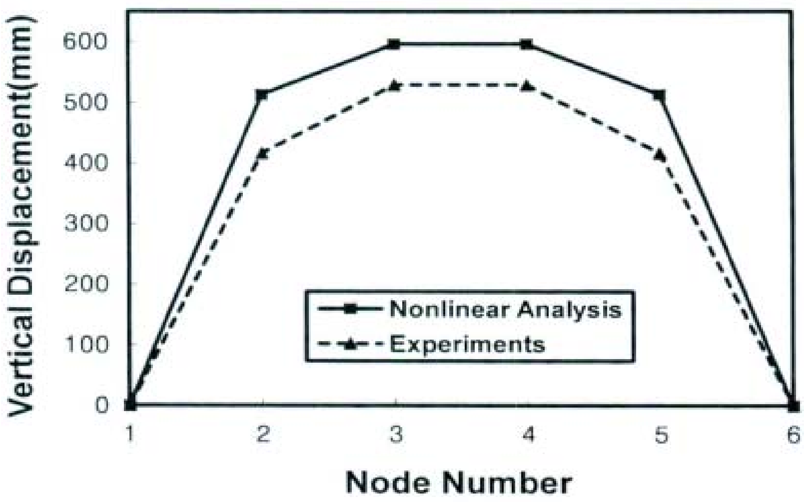
Photo 2: Final Shapes of Cable-tensioned and Shaped Space Dome

4. DISCUSSION

The final shape of the dome shaped space structures were obtained after closing the gaps in each bottom chords. In test model, the cable-tensioning force used for shape formation was small. With these results, the feasibility of the proposed method for dome shaped space structures has been presented by the comparative small cable-tensioning force. The results of nonlinear finite element analysis and the shaping formation tests are shown in the Figure 3. As shown in the Figure 3, we can predict the general trends for shaping behavior of space structure. In the model A, it is a good agreement between the theoretical values and experimental values. But in test model B, though the central part of test model was made in an octagon shaped grid to avoid the concentration of stress, the some differences are shown between the results of analysis and experimental results for central parts. Specially, in the model B, it is assumed that the big difference of shaping formation between the result of nonlinear finite element analysis and experimental result is owing to the joint rotation and the secondary stress as like a bending moment. As shown in Photo 3, some members are curved for the process of shaping formation, and some joints are rotated after shaping formation. With this consideration, though there are some discrepancies, these studies could be shown the possibility of shaping formation by cable-tensioning. Generally, in the shaping formation, some discrepancies between the theory and experiment exist due to the geometric imperfections, the rotations and slippage of joints, and the weakness of top chords stiffness owing to the bolt holes at joint in the test model. But as a mentioned above, nevertheless these imperfections affect the structural behavior of the shaping formation. Consequently, for the improvement of the efficiency in the finite element method for simulating the structural behavior of shaping formation of space structure involving mechanism or near-mechanism, further research is necessary.

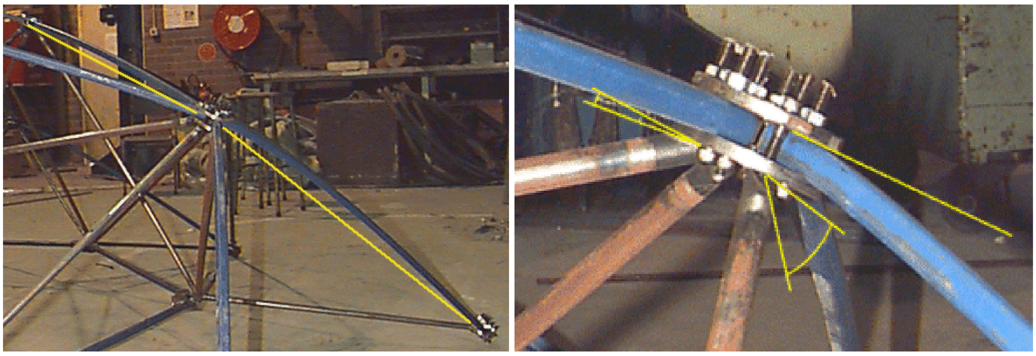


(a) Model A



(b) Model B

Figure 3: Shape and Deflection of Top Joints in Models



(a) Curved Member *(b) Joint Rotation*

Photo 3: Deformed Shape by Bending Moment and Joint Rotation in Model B

5. CONCLUSION

Based on the studies carried out here, the following conclusions for the experiments and analysis can be drawn :

The feasibility of the proposed method for shaping formation in a dome shaped space structure has been presented. The shape formation process is integral with the erection process.

A cable-tensioned and shaped space dome has evident advantages because economic and time saved construction technique compared with the conventional techniques using a big crane or scaffold for erection.

A nonlinear finite element analysis method for predicting the space shape and the experimental result for dome shaped space structures is presented, in the future, the some discrepancy in the results between theory and experiment could be studied.

For the large scale model, it should be assumed to consider the secondary stress as like a bending moment, further research is necessary in the future.

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A CONCEPTUAL FRAMEWORK FOR STRATEGIC MANAGEMENT OF CONSTRUCTION FIRMS

B. Er
Akdeniz University, Antalya, Turkey, bayramer@akdeniz.edu.tr

A. Kazaz
Akdeniz University, Antalya, Turkey, akazaz@akdeniz.edu.tr

S. Ulubeyli
Bulent Ecevit University, Zonguldak, Turkey, serdar.ulubeyli@karaelmas.edu.tr

Abstract

Construction industry has a competitive and dynamic environment, including different professions and trades. It is also in a direct and indirect relationship with more than 30 sub-sectors. Because of this complicated working environment, construction firms are very prone to any changes that can occur in internal and external environment, such as capital, experience, technology, economics, politics, etc. In order to gain competitive advantages against these changes, construction firms need to have a vision to maintain their competitive and dynamic positions, and thereby to construct appropriate strategies. In this study, a conceptual strategic management framework was developed for construction firms operating in the construction industry. This framework was supported by a decision making matrix. Based on this matrix, different scenarios and the corresponding strategies were presented.

Keywords: decision making matrix, construction industry, construction firms, strategy, strategic management, competitive advantage, conceptual framework.

1. INTRODUCTION

The construction industry has a competitive and dynamic environment, and includes different professions and trades. It is also in direct and indirect relationships with more than 30 sub-sectors. Due to this complicated working atmosphere, construction firms are very sensitive to any changes that occur in internal and external environment, such as capital, experience, technology, economics, politics, etc. In order to gain competitive advantages against these changes, construction firms need to have a vision to maintain their competitive and dynamic positions, and thereby the corresponding strategies.

According to Betts and Ofori (1992), the long-term survival of large-scale firms depends on an effective strategic management application. Although construction firms do not pay the required attention to strategic management (Cheah et al., 2004), in the last two decades it has become widespread among large-scale construction firms to assign more resources to strategic thinking (Price et al., 2003). Numerous academic researches confirm this argument (Betts and Ofori, 1992; Warszawski, 1996; Chinowsky and Meredith, 2000; Yisa and Edwards, 2002; Dikmen and Birgonul, 2003; Price and Newson, 2003; Price et al., 2003; Cheah and Garvin, 2004; Cheah et al., 2004; Danosh, 2005; Naaranoja et al., 2007; Kazaz and Ulubeyli, 2009; Abu Bakar et al., 2011). The main reason for neglecting strategic management is that the management staff of construction firms solely focuses on the execution of construction projects instead of managing daily operations (Chinowsky and Meredith, 2000; Danosh, 2005).

Many strategic management practices in different countries have been examined to date (Yisa and Edwards, 2002; Dikmen and Birgonul, 2003; Price et al., 2003; Danosh, 2005; Kazaz and Ulubeyli, 2009; Abu Bakar et al., 2011). The common result of these studies is that strategic management is generally utilized by large-scale construction companies and neglected by medium- and small-scale ones. Therefore, the aim of this study is to develop a conceptual strategic management framework for construction firms.

2. BACKGROUND OF STRATEGIC MANAGEMENT

The term strategy was first used in ancient Greece and was defined as the art of planning and managing campaigns by the military (Hill and Jones, 1995). At the beginning of 1920's, the manufacturing industry started to utilize this concept and then various researchers suggested different definitions. Although there is no universally accepted definition of strategy, an early definition was provided by American business historian Chandler (1962) as follows:

"*Strategy is determining a firm's long-term objectives and goals and preparing activity plans to achieve these goals*".

Mintzberg (1978) described it as a series of product and market decisions and activities. According to Porter (1980), it is decisions and activities to overcome competitors in the market. The common idea of these definitions is that strategy is an art of decision making. Here, the aim is to select appropriate activities that will help firms to survive in the market and/or increase profitability. The characteristics of strategy can be listed as follows:

- Strategy is an art of analyzing,
- Strategy is an element based on goals,
- Strategy organizes the relationship between firms and their environment,
- Strategy is interested in future, but not in repetitive activities,
- Strategy manages all of financial and human resources,
- Strategy determines the roadmap.

Strategic management can be defined as planning, organizing, implementing, coordinating, and controlling activities that organizes a firm's relation with its environment and determines its direction within the market. Abu Bakar et.al. (2001) divides strategic management into three stages: (i) formulation, (ii) implementation, and (iii) evaluation and control. Each activity that should be carried out in each stage is listed in Table 1.

Phases	**Activities**
Formulation Phase	Observing the changing environment
	Determining opportunities and threats introduced by the environment
	Determining strengths and weaknesses
	Determining vision and goals
	Determining strategies for achieving goals
	Choosing appropriate strategies
Implementation Phase	Strategic planning
	Establishing an organizational structure to realize the strategies
Evaluating and Control Phase	Evaluating performance

Table 1: Strategic management phases and their activities

According to Venegas and Alarcon (1997), the economy theory that the strategic management literature is based on is not easy to implement in the construction industry. Male and Stocks (1991) stated that organizational structures that are developed based on the strategy theory are useful for firms operating in the manufacturing industry. Therefore, the terms related with strategy should be re-defined for the construction industry to effectively implement strategic management.

3. GENERAL CHARACTERISTICS OF CONSTRUCTION FIRMS

Firms operating within the construction industry can be classified into three groups:

- Firms operating in another industry and entering the construction industry later,
- Firms operating in the construction industry and entering in another industry later,
- Firms operating in the construction industry only.

The first two types of firms are mostly large-scale and have a professional organizational structure. Strategies developed by these firms depend on strategies developed for other industries. In other words, these strategies can be alternatives for these firms to achieve their goals. In this study, only the third type of firms was taken into account. Within the scope of the present study, it was aimed to develop a conceptual strategic management framework for these firms, which will help them to survive in the industry and/or increase profitability.

Construction companies give proposals to execute their customers' projects. This means that they are searching for customers before the product is produced, but not after completing the product. This structure of the industry leads to three main uncertainties as follows:

- *Uncertainty on Continuity:* There is no continuity in the production process. Production is interrupted between the end of a project and the start of a new one. If the interruption time increases, then the construction firm is affected negatively.
- *Uncertainty on Capacity:* Especially in the manufacturing industry, the amount of product, labor, equipment, and material is pre-determined and almost stable. However, in the construction industry, these capacities vary from project to project based on the project scale. The capacity uncertainty appears in two forms: over capacity and insufficient capacity. In case of over capacity, the expenditure increases because firm has to pay for the idle capacity. In case of insufficient capacity, the profit decreases because extra resources have to be employed.
- *Financial Uncertainty:* This uncertainty is correlated with continuity. If the production is interrupted, then the income is interrupted. The lack of a stable cash flow hinders companies to establish long-term goals.

Strategies of construction firms should remove or reduce the impact of these uncertainties. Accordingly, vision and primary strategy of these firms should be in a position where they can give proposals to more projects. In this regard, construction firms have to evaluate their own competencies and requirements of projects.

4. CONCEPTUAL FRAMEWORK FOR STRATEGIC MANAGEMENT

Construction firms should first answer the following questions before determining their strategies:

1. What should be the size of projects that they will give proposals, considering their resources?

2. Why should clients prefer them?

In fact, the content of these questions are similar, but their points of view are different. The first question indicates the firm's (internal) viewpoint, while the second denotes the employer's (external) viewpoint. Since the aim of this conceptual framework is to determine projects to which construction firms can give proposals, the internal viewpoint should reflect firms' core competencies required to execute projects. In this context, construction firms should evaluate their core competencies related with the project execution in terms of the following aspects:

- Material supply,
- Material diversity,
- Compliance to the industry,
- Reliability in the industry,
- Experienced managerial personnel,
- Sufficient equipment,
- Outsourcing capacity for machines,
- Sufficient labor force,
- Outsourcing capacity for labor force,
- Benchmarking,
- Political support,
- Financial capacity,
- Competence in finding financial resources,
- Product quality,
- Productivity,
- Establishing joint ventures,
- Competence in working in different locations,
- Competence in working abroad,
- Work experience,
- Experience in complex projects,
- Use of information technologies,
- Design and technical experience.

In fact, a firm's competencies indicate the upper limit it can afford to execute a project. Therefore, in order to determine whether a firm is competent to execute a specific project, its requirements (i.e., external viewpoint) should also be evaluated by the firm. Project requirements can be categorized under two groups: requirements for executing the project, and requirements related with the project environment. In this context, the following aspects of a project should be considered:

1. Project execution conditions

- Project cost,
- Project duration,
- Required labor force,
- Required equipment,
- Types of materials,
- Types of construction technologies (formwork type, etc.),
- Complexity of the project,
- Size of the project,
- Type of project (housing, dam, road, etc.),
- Location of the project,
- Receive progress payments on time,
- Incentive premium.

2. Environmental conditions

- Competence of the rivals,
- Taxes,
- Permits,
- Economic uncertainty,
- Political uncertainty.

Finally, by comparing internal and external viewpoints, construction firms can easily determine projects that they can give proposals. For this objective, a matrix was developed to facilitate the decision making process (Table 2). In the matrix, internal aspects are listed in the rows while external aspects are shown in the columns. This structure of the matrix provides an overall viewpoint of the project and facilitates the decision making procedure.

In the Statement row, qualitative or quantitative requirements of the project can be entered. Quantitative requirements are those that can be expressed by numbers, such as labor force requirements, project cost, or project duration. Qualitative requirements are more subjective, and therefore, the estimator should suggest proper statements. For example, the scale of a project is a relative statement. In this case, the estimator should make a comparison between previous projects and the new one, and fill the box as competent or not competent.

The grey boxes on the matrix show the relationship between internal and external aspects. These boxes should be filled by the estimator to make a comparison between the statements of each requirement. For example, assume that 100 workers are required to execute a project and that a firm can meet this requirement. In this case, the firm can be regarded as competent. By comparing internal aspects with external ones, the firm can easily determine if it can execute the project or not.

This matrix can also be used to determine which internal aspects should be improved to increase the project range and develop proper strategies. Different strategies are suggested to construction firms under different scenarios as follows:

– *Project with high cost and without advance payment:* In this scenario, if a construction firm cannot execute a project with its own capital, then it has to develop strategies for finding financial recourses or to determine partners with which it can establish a joint venture.

– *Project that has insufficient labor force:* If a construction firm meets the other requirements of a project, then it will try to increase the labor force capacity. Before increasing this capacity, some factors such as project duration, separation payment, and the employment of over capacity, should be considered. If increasing the capacity is not useful, then subcontractors or joint ventures should be determined.

– *Lack of experience in international projects:* A construction firm that has a desire to execute projects abroad has to evaluate its compliance to the host country’s construction industry and develop strategies to eliminate local and cultural shortcomings. Another strategy for this scenario is to determine local construction firms to establish joint ventures.

Activities performed until this stage is of the formulation phase of strategic management. Implementation phase is carried out by determining and performing activities to realize strategies. However, the most important phase in strategic management is the evaluation and control phase. In this stage, qualitative evaluations made before the project are compared with the real data obtained after the project. This comparison enables construction firms to determine their shortcomings and develop new strategies for future projects. Strategies that should be developed for a sample scenario are explained as follows:

– *Time overrun:* Main factors affecting the duration of construction projects are labor force and machine capacity, material supply, legal permissions, work flow, and cash flow. In this case, reasons of time overruns should be determined, and preventive measures should be developed for future projects. For instance, if material supply is the reason of time overrun, then construction firm should search for alternative material suppliers. Similarly, if the reason is low capacity, then it should develop strategies to increase the capacity.

In fact, strategic management in construction firms provides continuous improvement. With the experience gained by projects, construction firms can eliminate their drawbacks and thereby give proper proposals to more projects.

	Project Execution Conditions												**Project Environmental Conditions**				
	Project cost	Project duration	Required labor force	Required machine and equipment	Types of materials to be used	Types of construction technologies	Complexity of the project	Size of the project	Type of project	Location of the project	Receive progress payments on time	Incentive premium	Competence of the rivals	Taxes	Permits	Economic uncertainty	Political uncertainty
Statement =>																	
Competency																	
Financial capacity																	
Competence in finding financial resources																	
Production rate																	
Sufficiency of labor force																	
Outsourcing capacity of labor force																	
Sufficiency of machine park																	
Outsourcing capacity of machine																	
Material supply																	
Material diversity or variety																	
Product quality																	
Experienced managerial staff																	
Work experience																	
Experience in complex projects																	
Design and technical experience																	

Use of information technologies																	
Political support																	
Compliance to the sector																	
Competence to work in different cities																	
Competence to work abroad																	
Establishing joint venture																	
Benchmarking																	
Reliability in the sector																	

Table 2: Decision making matrix

5. CONCLUSION

The construction industry differs from other industries because of its unique structure. Although it is one of the leading industries of economies, uncertainties and high competitive environment make it very risky and difficult to survive in the industry.

Firms' visions are crucial for survival, and strategies are the main ways to achieve these visions. In this context, determining proper strategies and implementing and managing them effectively have an important role in the overall firm success. On the other hand, since economy theory and organizational structure in the manufacturing industry are not appropriate for the construction industry, the theory should be re-defined.

Lack of continuity, uncertainty in capacity, and discontinuous cash flow make difficult to determine long term visions in the construction industry. In this regard, enlargement of construction firms can be provided by short term strategies. Therefore, the vision of construction firms should be in a position where they can give proposals to more projects.

In order to determine projects that firms can give proposals, companies have to evaluate and compare their internal competences and project requirements. For facilitating this process, a decision making matrix was developed. With this matrix, construction firms can easily determine projects that they give proposals and develop proper strategies by considering their drawbacks before and after the execution.

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AN INFORMATION-FLOW-BASED ORGANIZATIONAL FRAMEWORK TO STREAMLINE THE PROCESS OF EMPLOYING BIM WITHIN CONSTRUCTION PROJECTS

Chung-Wei Feng
National Cheng Kung University,Tainan,Taiwan (R.O.C.), cfeng@mail.ncku.edu.tw

Ya-Ting Ho
National Cheng Kung University,Tainan,Taiwan (R.O.C.), dnahwen@gmail.com

Abstract

The AEC industry today is highly fragmented, which stakeholders collaborated with different technologies to achieve common goals. When carrying through a project, effective information communication and coordination among stakeholders still is a challenge because the traditionally linear procedure cannot transfer and integrate the information in the timely fashion. BIM is an emerging development, and serves as the information sharing repository to shift the traditional processes into a model-based mechanism to better information transfer. However, studies still show information flows among stakeholders at various processes should be identified within stages of the project lifecycle to assure the success of construction projects. In addition, information exchanges, responsibilities, and authorities, should also be determined. Therefore, it is necessary to analyze the relationships between stakeholders in different processes in terms of information flows to develop an organizational framework for the BIM-based construction project. A research on developing the organizational framework of employing BIM technology in terms of information flows is conducted. First of all, we analyze the organizational framework based on IIS scope among stakeholders in the project during the construction phase. Then International Defense Industry Fair (IDEF0) is used to depict a new BIM-based design process. We decompose the BIM modeling process in order to analyze the information flow and information needs of project stakeholders. BIM software has limited application nowadays, hence we shift the BIM model information to the database, and help stakeholders define and refine their information needs in a proper way.

Keywords: BIM, IIS, information flow, organization.

1. INTRODUCTION

In the early development of BIM, single project stakeholders could only take advantage of this technology independently for their own benefit. For example, some researchers have outlined the benefits of BIM to the different fields of the AEC industry such as design authoring (Tardif, 2008), 3D coordination of different fields (Staub, 2007), dynamic cost estimation (Autodesk, 2007), building system analysis (Autodesk, 2007), 4D planning and site utilization analysis (Chau et al., 2004; Heesom & Mahdjoubi, 2004), sustainability analysis (Azhar et al., 2011), digital fabrication (Rundell, 2008), construction safety analysis and management (Zhang, & Hu, 2011), and etc.

Later on, researchers started to explore the potential value of BIM as an information integration tool between different processes and stakeholders, hence many organizations such as AIA, AGC, and CIC have developed guidelines to facilitate and standardize BIM adoption (AIA, 2007; ACG, 2006; CIC, 2010). These studies can be considered as the generic BIM implementation in the AEC industry, but still with the limitation of improving the process of applying BIM with construction projects and information flow within the organizational framework.

Therefore, it is necessary to analyze the relationships between stakeholders in different processes in terms of information flows to develop an organizational framework for the BIM-based construction project.

A research on developing the organizational framework of employing BIM technology in terms of information flows is conducted. First of all, we analyze the organizational framework based on IIS scope among stakeholders in the project during the construction phase. Then IDEF0 is used to depict a new BIM-based design process. We decompose the BIM modeling process in order to analyze the information flow and information needs of project stakeholders. BIM software has limited application nowadays, hence we shift the BIM model information to the database, and could help stakeholders define and refine their information needs in a proper way.

2. THE INFORMATION INTEGRATION SPHERE (IIS)

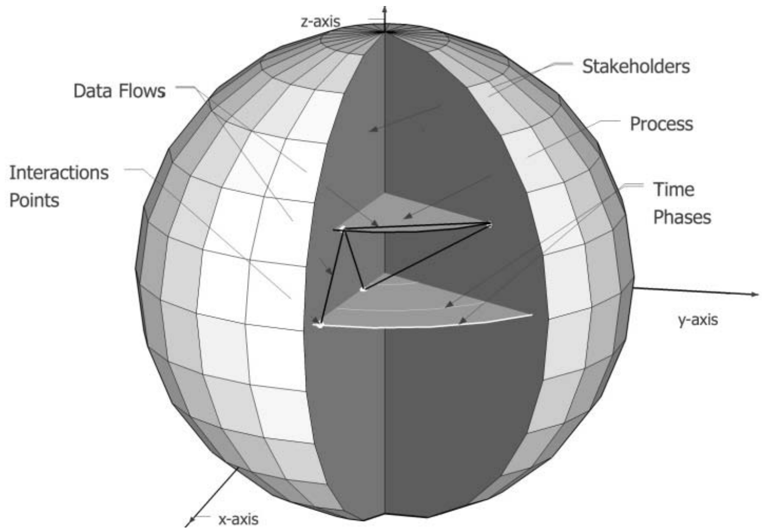

Figure 1: IIS components

The IIS is an information-modeling tool that can generate, manipulate and visualize the flows between different processes using BIM technology. The IIS geometry is similar to that of a sphere, in which the information starts in the center point of the sphere and evolves according to the increasing size of the sphere (as shown in Figure 1).

Timeline, process, stakeholder, and data flows are the four components of the IIS model. The graphic representation of those components can be found in the following paragraphs.

2.1 Timeline

It's the graphic representation showing the passage of time. In the IIS model, timeline represents the time where an interaction or exchange of information take place between different stakeholders or processes (as shown in Figure 2).

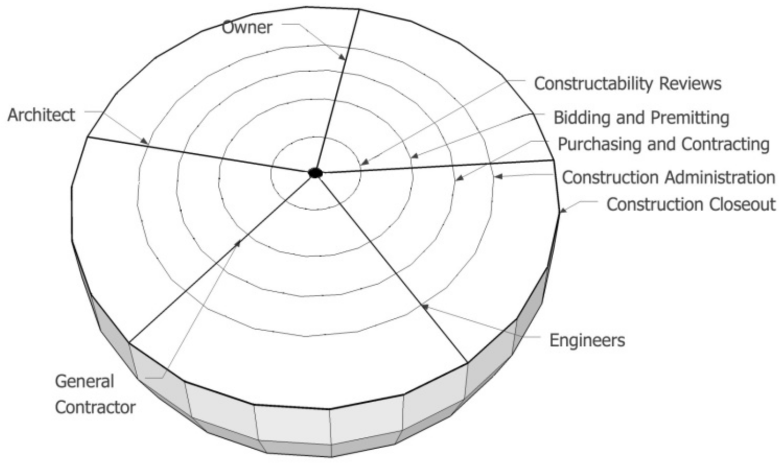

Figure 2: Timeline and Stakeholders of IIS

2.2 Stakeholder

Stakeholder could be an individual person or an organization that participates in the information exchange within the construction project. These stakeholders may include the owner, engineers, architect, project manager, and suppliers, etc (as shown in Figure 2).

2.3 Processes

Processes are a serious of actions changes or functions bringing about a result. It's a set of transformations of input elements into output elements with specific properties, with the transformations characterized by parameters and constraints. Graphically the process in IIS is defined as horizontal planes cutting the sphere parallel to the x-y plane (as shown in Figure 3).

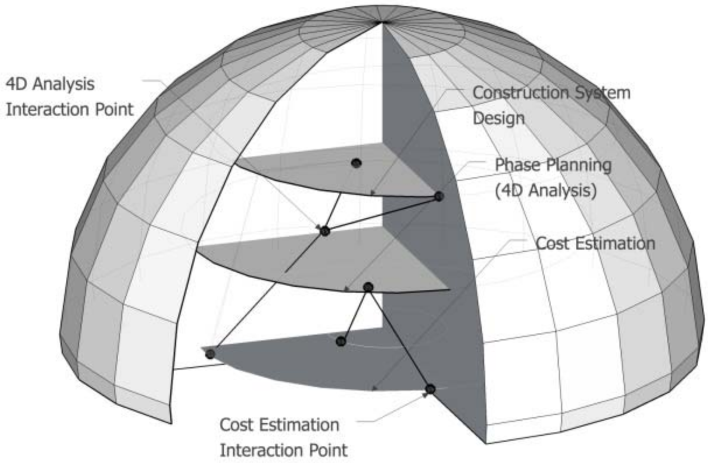

Figure 3: Process and Data flow in the IIS

3. MODEL PROGRESSION SPECIFICATION

The Model Progression Specification (MPS) is the common language that project stakeholders from different parties can use to communicate with each other. There are three main factors in the MPS: the stakeholders, the communication, and the language, that do play roles in the MPS and BIM implementation. Project stakeholders from different parties, like the owner, architect, contractor and so on, collaborate together to reach to project goals and thus form the organizational framework. The communication indicates the information exchange which shows not only the process happened between stakeholders but also reveals the information needs from the stakeholders. And the language here is more like the important aspects that stakeholders must pay much attention to, and even more like the implementation or realization of the information needs from the stakeholders. The cost and schedule issues, as well as the BIM components are three of the most important aspects we focus in this research.

There are a lot of information flows in a construction project, and the stakeholders in related organization may feel too hard to deal with them timely. Therefore this research works to streamline the process by employing BIM, IIS methodology, and approaches in the following three sections: the organizational framework, information flows, and the database.

3.1 Organizational Framework

This research focuses on the organizational framework within construction projects in terms of the interaction among different stakeholders and uses the IIS methodology as the theoretical basis. There are different stakeholders in the construction organization bring to their varied objectives. The information flows do occur mechanically to complement the stakeholder's information requirements within the organizational framework. IIS helps to virtualization, for instance, two vertical slices indicate two unique stakeholders while the horizontal planes indicate different processes, and the lines indicate the information flows as well as the information exchanges in between. (as shown in Figure 4).

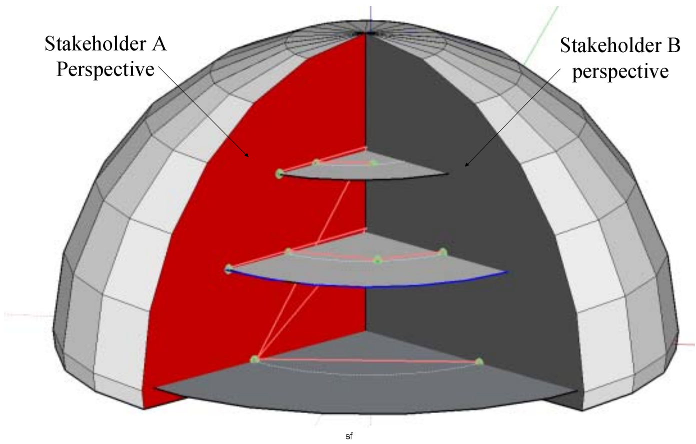

Figure 4: Organizational framework of stakeholders

To streamline the process of employing BIM, first of all, we starts to identify the main stakeholders in terms of their objectives using IIS approach. This identification helps clarify the exchange of information that will be involved in different stages and phases as well as between stakeholders (as shown in Figure 5).

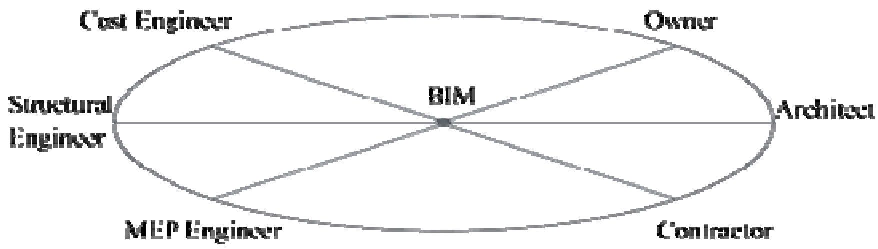

Figure 5: Organizational framework of stakeholders

While we analyze the organizational framework regarding BIM information exchange, stakeholders in the project including the owner, architect, contractor, MEP engineer, structural engineer, and cost engineer are considered during the construction phase. And we setup different objectives for the stakeholders as their information needs. These objectives, taking the construction management into account, may include: streamline the organizational workflow, control the budget and cost, balance the quality with duration, and so on.

3.2 Information Flows

The research would like to decompose the BIM modeling process in order to specify the information flow and information needs within the project stakeholders. International Defense Industry Fair (IDEF0), a modeling language, is used in this research to depict a new BIM-based design process.

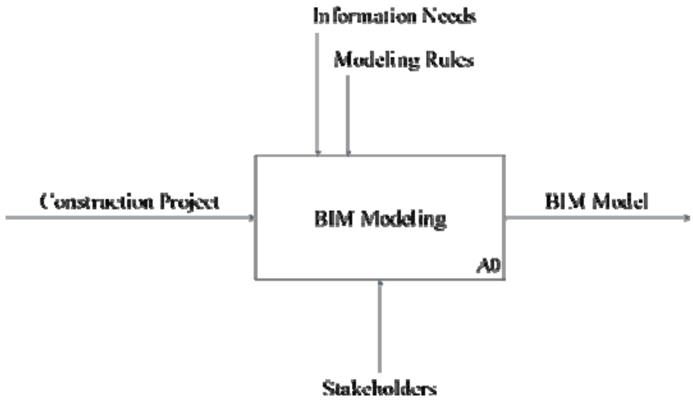

Figure 6: IDEF0 process analysis

The presented IDEF0 model tells the prototype of this research (as shown in Figure 6). Start from the activity, A0: BIM modeling, shows our ultimate goal as to streamline the process of employing BIM; the input is the construction project while the output is the BIM model; the controls are the information needs and modeling rules as well as the mechanisms are all the stakeholders.

3.3 Database

BIM software has limited application nowadays, hence we shift the BIM model information to the database, and help stakeholders define and refine their information needs in a proper way. By taking the characteristic of database into consideration, we design a new structure combined with the BIM component, the schedule data, the cost data, and the trade data. Although their relationship can be too complicate each pairs, with Microsoft Access, we therefore normalize the dependence and arrange the relationship tables (as shown in Figure 6). The main criteria of the database are:

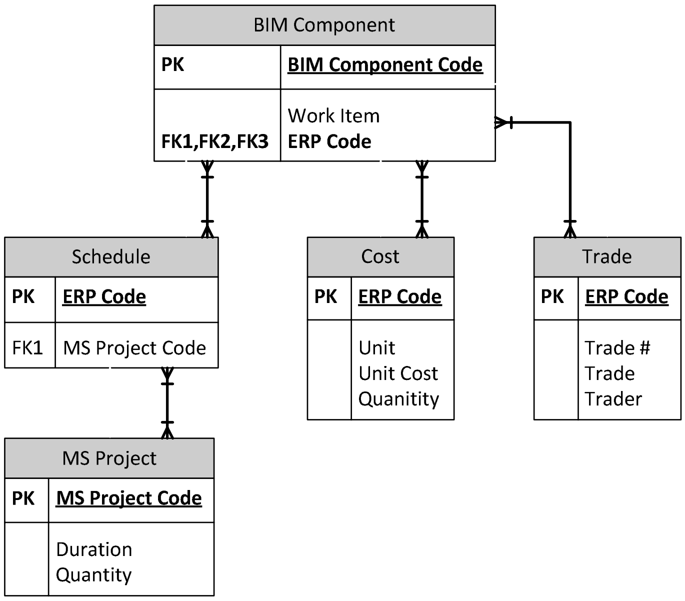

Figure 7: Access database relationship

- BIM component, including BIM Component Code, Work Item, and ERP Code
- Schedule, including ERP Code and MS Project Code, duration, and Quantity
- Cost, including ERP Code, Unit, Unit Cost, and Quantity
- Trade, including ERP code, Trade Number, Trade Name, and Trader

Here are some related attributes combined with the BIM component such as the code, trade, WBS, item, unit, quantity, unit price, total price, and trade contractor data within the database framework (as shown in Figure 8).

Budget Code	Trade	SAP WBS Code	Item	Unit	Quantity	Unit Price	Total Price	Relationship	Subcontractor	Calculation based on Item
CB29	26Structural Steel	R-12B003-00-70-10-01	NonDestructive Testing	Uniformity	1	207371	207371	No Correlation	Century Iron and S	Need to Confirm with RSEA
CB30	26Structural Steel	R-12B003-00-70-10-02	Steel Inspection	Uniformity	1	207371	207371	No Correlation	Century Iron and S	Need to Confirm with RSEA
A1601	00Miscellaneous	R-12B003-10-60-40-01	Traffic Maintenance Fee an	Uniformity	1	76190	76190	No Correlation	Long Yun Security	Need to Confirm with RSEA
A0901	00Miscellaneous	R-12B003-10-60-60-01	Sewage Treatment Fee	Uniformity	1	30000	30000	No Correlation	Mei Duen Enginee	Need to Confirm with RSEA
A02	No Information	R-12B003-20-10-30-00	Land Appraisal Fee	Uniformity	1	12000	12000	No Correlation	No Information	Need to Confirm with RSEA
A01	Lie in Sub-Item	R-12B003-20-10-30-01	Constructiin Lofting	M2	12738.1	40.67797	518160	Direct Correlation	Tung Jie Engineeri	Need to Confirm with RSEA
A0101	24Plate	R-12B003-20-10-30-01-01	Lofting_ Under Ground (Re	M2	6801	50	340050	Direct Correlation	Tung Jie Engineeri	The Area of Mat foundation,E
A0102	24Plate	R-12B003-20-10-30-01-02	Lofting_Over Ground (Stee	M2	5937	30	178110	Direct Correlation	Tung Jie Engineeri	The Area of 1FL-RF
A03	Lie in Sub-Item	R-12B003-20-10-50-01	Land Levelling	Uniformity	1	65550	65550	No Correlation	Lie in Sub-Item	Need to Confirm with RSEA
A0301	15Earthmoving Ma	R-12B003-20-10-50-01-01	Excavator	Day	2	12000	24000	No Correlation	Wan Yi Transport	Based on Rental Day

Figure 8: Access database

4. CONCLUSIONS

This research discussed an organizational framework of employing BIM technology in terms of information flows. By analyzing the organizational framework based on IIS scope, using IDEF0 to depict a new BIM-based design process, and shifting the BIM model information to the database, the information exchanges, responsibilities, and authorities within the construction project could be clearly determined.

With the implementation of this organizational framework, the construction management goal is achieved, and moreover the information transition is integrated into an efficient and seamless way.

Because the organizational framework is a pioneer research, in the future it could be linked to all the building's components and used to automatically generate stakeholders' data requirements and responsibilities for the whole lifecycle of the project.

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CRITICAL CHAIN METHODOLOGY IN CONSTRUCTION PROJECT MANAGEMENT: A PRACTICAL FRAMEWORK

Chung-Wei Feng
National Cheng Kung University,Tainan,Taiwan (R.O.C.), cfeng@mail.ncku.edu.tw

Gabriela Andrade Lam
EP Petroecuador, Ecuador, gaby16lam@hotmail.com

Ya-Ting Ho
National Cheng Kung University,Tainan,Taiwan (R.O.C.), dnahwen@gmail.com

Yi-Jao Chen
University of Kang Ning, Tainan,Taiwan (R.O.C.), yjchen1212@gmail.com

Abstract

Critical Path Method (CPM) has been used in construction industries for a long time, but delays and overruns still happen. Goldratt developed the Critical Chain Project Management (CCPM), which proposed a solid theoretical background to deal with uncertainties within projects to avoid time overruns by addressing human behavior issues along with the schedule development. CCPM was designed for applying in many industries or projects by following a generic procedure that focuses mostly on human resource and its uncertain behavior. Some of the concepts addressed are the reduction of activity durations, the elimination of the Student Syndrome and Parkinson's Law, the elimination of resource conflicts and multitasking. However, in construction projects, it is very common for project managers to subcontract works. Subcontractors are only hired for a certain period of time to perform specific tasks according to the contract, so it is not logical to expect subcontractors to voluntarily reduce their original estimated durations. In addition, cost issues should not be left apart. Construction projects are highly sensitive to variations on schedule and cost. This research presents a practical framework according the proposed bonus system to employ CCPM to construction projects. First, the difficulties of applying the critical chain to construction projects are addressed. Then, the approach developed to implement the critical chain to the construction project management is described.

Keywords: critical chain, critical path method, construction project management.

1. INTRODUCTION

The project success in any industry or business is not a new concern. Companies and individuals have always tried to find a solution in order to get the best project performance, which is mostly reflected in associated costs, time required for completion and the quality of finished products. Even though there are several techniques to achieve optimal performances, failures are still common among in projects of all types. There are many different methodologies that have been used for project management. So far, one of the most common scheduling techniques nowadays is the Critical Path Method (CPM), which has been used for long time within many industries, but delays and overruns still happen when using it.

Goldratt (1997) developed the Critical Chain Project Management (CCPM), which provides a solid theoretical background to deal with the uncertainties within projects and avoid time overruns by addressing human behavior issues along with the schedule development. It was designed for applying to any kind of industry or project by following a generic procedure that focuses mostly on human resource and its uncertain behavior and basically ignoring cost management. Some of the concepts addressed are the reduction of activities durations, the elimination of the Student Syndrome and Parkinson's Law, the elimination of resource conflicts and multitasking. The theory advocates a change in the human behavior patterns on all the team members – including labor – in order to improve project performance, by the means of transferring knowledge and getting people involved in the process, encouraging the human resource to go against the behavioral inertia and avoid the harmful effects over the project results. However, every industry faces its own variables and ignoring these particularities make the methodology somehow abstract to apply. In construction projects, it is very common for general contractor to subcontract jobs to different trades. Those subcontractors do not belong to the general contractor in a permanent or direct status. Subcontractors are only hired for a certain period of time to perform specific tasks before the contractual relation ends, so it is not logical to expect subcontractors to dutifully follow guidelines about how to handle their own staff and voluntarily reduce their usual estimated durations. In addition, executing construction project is profit-oriented, cost issues should not be left apart. Construction projects are highly sensitive to variations on schedule and cost, hence a bad management on these issues can turn a successful project into a disaster.

The paper is organized as follows: first, the problematic within construction project management is presented, including the difficulties being faced by the construction project manager and the use of critical chain as a scheduling tool to improve project performance. Next, a brief review about the basic precepts of the critical chain theory is held. Then the practical approach developed as part of this research to ease the implementation of critical chain in construction project management is described. And finally, the conclusions and suggestions that arose at the end of this study are explained.

2. PROBLEM STATEMENT

Through years, there has been a rapid growth of project management. Although several methodologies have been developed and used for different scenarios and industries, project failures are still common in both small-and-large-scale projects. Construction industry does not flip out of this tendency. The reasons of delay and cost overrun have been studied and analyzed with aims of finding a solution that prevents project failures. Several researchers have tried to determine the causes of delays in the construction industry: N. R. Mansfield (1994) describes delays causes for the case of Nigerian construction projects; Chan and Kumaraswamy (2002) presents the observations from previous studies about causes of delays in different areas of the world, including the United States, United Kingdom, Nigeria, Saudi Arabia, Hong Kong, Indonesia in developed and developing countries; Long et al. (2004) introduces the problems faced in construction projects in Vietnam as a developing country and ranks and categorizes them through questionnaires and numerical analysis; Sweis et al. (2008) summarizes the causes of delay in the Middle East region. The reasons of delay vary from one study to another, although they have some in common: those regarding to cost issues (financial problems), the ones that cannot be predicted (such as weather conditions), and also those about human resources and their interactions in the project phases.

One of the most used and widely spread methodologies used in construction planning is the Critical Path Method. However, issues of uncertainties and human resources are hard to be implemented within the CPM planning process. Goldratt (1997) advocated for a change of perspective over project management, in order to address those uncertainties leading to project failures. He proposed the Critical Chain Project Management by considering the effects in human behavior patterns that commonly affect project performance. This makes the Critical Chain Methodology an attractive tool for project management. However, even though critical chain supporters advocate that it can be easily adapted into any kind of projects, there is a lack of specific information regarding to its application in construction project management. It basically ignores cost management and focuses most on time management, as part of a flexible strategy to address human variability. There have been several reactions since this methodology was first introduced. Leach (2005) has described in great detail the application of this theory, by expanding the original understandings from the novel where it was stated (Goldratt 1997). Some researchers have reviewed and analyzed this technique on emphasizing its capabilities to improve the current practices of project management (Leach 1999; Rand 2000; Steyn 2000; Herroelen and Leus 2001; Herroelen et al. 2002; Steyn 2002, Wei et al. 2002; Lechler et al. 2005; Watson et al. 2007), as well as the integration with the PMBOK Guide methodology (Kendall et al. 2001). Even though this theory can be used for single project plan, Goldratt (1997) and Leach (2005) have also described the capability of using critical chain in a multi-project environment. Cohen et al. (2004) analyze the applicability and control of a multi-project scheduling by the use of control mechanisms and other alternatives.

Besides the general studies about critical chain, its advantages and disadvantages, few articles can be found with a specific target industry: the application of this methodology at Bosch Security Systems (CCTV) Eindhoven (Dilmaghani 2008); and a case study in high-risk industry maintenance (Bevilacqua et al. 2009). Within the field of construction project management, not much research has been found: Vrîncuț provided an overview of Critical Chain Management and construction projects in Romania (Vrîncuț 2009), Yang analyzed the feasibility of the applying CCPM to construction projects (Yang 2007) and Rogalska and Hejducki addressed the use of time buffers in construction projects when planning the Linear Scheduling Model (Rogalska and Hejducki 2007).

The theory proposed by Goldratt (1997) is indeed quite logic and sound, but there is a gap between the theoretical model and a practical way to implement it, due to the specific conditions of construction projects and the profit-oriented aspect that makes cost a very important and sensitive variable in construction projects. Therefore, it is necessary to develop a practical framework that allows general contractors to implement the critical chain methodology as the main scheduling tool.

3. PROPOSED FRAMEWORK

The framework developed in this research is created from the point of view of a general contractor to apply critical chain methodology as a scheduling tool in construction project management. Given that Critical Path Method is currently the most widely used scheduling tool, this approach takes it as a basis and incorporates additional subjects to turn an already-created CPM plan into a CCPM plan, and includes a cost strategy that works along with the schedule development to create a practical and comprehensive way of implementing the CCPM to construction projects.

3.1 Assumptions

The scenario for this research is set under the following assumptions:

– The contract to legalize the project terms has already been signed by the general contractor and the owner. Therefore, both delivery time and price have already been set, as well as the scope and technical requirements.

– The general contractor developed the project schedule in the pre-contractual stage by following the Critical Path Method.

– The pre-contractual cost estimation is based on usual cost decomposition methods then the contract awarded price can actually cover the cost items as in the traditional cost framework.

– The works required to complete the project are mostly, if not all, subcontracted.

– There is at least one subcontractor whose bid is significantly lower than other companies.

– No resource conflicts are presented within the project execution.

– Activity is performed by only one subcontractor, but one subcontractor can perform more than one activity.

3.2 Implementing CCPM in construction projects: possible difficulties

The fundamental concept of CCPM is that activity duration should be reduced to eliminate bad human behaviors that have long been cultivated and unconsciously encouraged. According to CCPM, the duration reduction would force the same resources already working in the company to be more productive by encouraging a behavioral change and there should not be any increase in resources. However, most of the construction projects are performed by subcontractors who are basically outsiders to the general contractor company. A reduction of duration would need to, would not be easy under the contract signed. The difficulties that the general contractor might face when trying to implement CCPM can be summarized as:

– Lack of knowledge of the Critical Chain theory; its differences from CPM and how it should be implemented.

– Strong inertia in human behavior, which leads people to struggle against any other practice than the one they are used to, even if they prove not to be effective.

– Lack of motivation and incentives to promote the change of patterns.

– Subcontractors and labor ignore the positive impacts and results of changing the usual behavior.

– Lack of commitment from the subcontractors, who are usually not aligned with the project goal but rather with their own particular interests.

The external and non-permanent nature of the construction resources definitely calls for the need of implementing CCPM to construction projects. A bonus system is introduced as an incentive tool for encouraging subcontractors, as well as a penalty system to discourage subcontractors.

3.3 Cost strategy along with CCPM

This framework is designed to make bonus payments feasible within the same contract awarded price without compromising any other cost. The bonus system has been divided in two different types according to their sources:

– Bonus 1: From the reduction of subcontracts actual cost, to be paid if subcontractors reduce time units of their activities (critical or non-critical).

– Bonus 2: From the savings in variable indirect cost, to be paid to subcontractors after the project completion, if the total project duration is actually reduced.

The calculation of bonus 1 is based on a trade-off analysis between the bonus rate and the time reduction of activities for each subcontract. It is assumed that the variable indirect costs are directly proportional to the project duration, hence if the duration reduction is achieved, the savings from this cost item can be transferred as bonus 2.

3.4 Bonus 1

As described before, the money to pay this type of bonus comes from the initial sum allocated for subcontracts cost which was estimated in the pre-contractual stage. This initial amount is split into subcontracts and a reserve for the bonus, which can be done by reducing the subcontract referential price from its initial estimation –after the general contractor has won the contract and wants to hire the subcontractors- in order to receive lower bid offers and therefore reduce the subcontract actual price.

Consider any subcontract *i* for analysis, the maximum available funds for the whole project are basically considered to be the same as the subcontract price SCA_i. Of course, general contractor usually issues the subcontract price by abstracting his or her profit from the contract price issued by project owner. In addition, the referential bid price of any subcontract *i*, SCR_i, represents the maximum reduction of any subcontract price, it is *subjective* and depends on how much the general contractor would lower the bid prices for a specific subcontract, given the market environment and the knowledge of previous experiences. At this point of the plan, the general contractor does not know for certain the exact subcontract price, thus the maximum bonus (BA_i) for any subcontract *i* is based on the referential price SCR_i as follows:

$$BA_i = SCA_i - SCR_i \tag{1}$$

Where BA_i is the maximum monetary amount that will be available for bonus for subcontract *i*.

<u>Bonus rate</u>

Even though the original critical chain methodology suggests a 50% reduction of all activities' duration as time buffers (Goldratt 1997), the proposed approach dismisses a single fixed reduction rate for all activities. Instead, the duration reduction is addressed within the time-cost trade-off analysis, which is directly related to the bonus system.

Refer to Figure. 2. Point A denotes the initial set of time-cost for any subcontract *i*: the referential price SCR_i (which is lower than the available sum SCA_i) and the original duration as calculated in the CPM schedule. Point B's vertical coordinate corresponds to the maximum sum that the general contractor can afford to pay and the reduced duration to be defined. The trade-off analysis is performed in order to determine point B's horizontal coordinate, since the objective is to get a realistic percentage of reduction (within technical and logistic requirements) while at the same time get an attractive bonus rate for encouraging subcontractors to adopt this required reduction.

The difference between the available sum for the subcontractor SCA_i and the referential price SCR_i is the available amount for bonus BA_i, as expressed in equation 2. The bonus rate per time unit that the subcontractor i can get by reducing one time unit on any of its activities can be determined as follows:

$$B_i = \frac{BA_i}{\sum_{j=1}^{n} r_i \times D_{i,j}} \quad (2)$$

Where:

r_i = Percentage of reduction of all the activities of subcontract i (%)

$D_{i,j}$ = Duration of activity j corresponding to subcontract i (time units)

j = Number of activities in which subcontractor i is involved

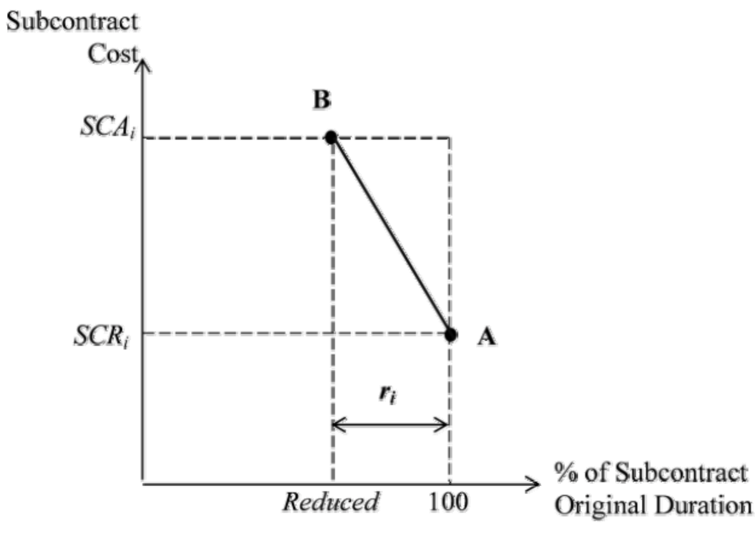

Figure 2: Trade-off between duration reduction and subcontracts cost

Basically, the trade-off shown in equation (2) is determined by the percentage of reduction ri, and the bonus rate Bi. The idea is to set one reduction rate for each subcontract, which will be applied on all the activities in which the subcontractor is involved in, in order to homogenize the reductions to be required to the subcontractor, as well as having a unique bonus rate to be paid per each day reduced on these activities. All the remaining elements of equation (2) are actually fixed values that cannot be changed: SCAi is the maximum amount that the general can really pay; SCRi is the referential price which is defined subjectively and depends on market environment and the general contractor's previous experiences; and Di,j is the duration determined from the original Critical Path schedule.

It is important to point out that in order to be consistent, the denominator of equation (2) cannot be lower than 1, otherwise the bonus rate would result in a higher value than what the general contractor actually has. The values gotten when multiplying the percentage of reduction times the duration of an activity are rounded, in order to get integer day values that are easier to control during the project execution phase. It should be noted that this is not a search for an optimal value, instead, the intention of this approach is to give to the general contractor a flexible and practical strategy, a range of options from which to choose the most suitable one, where the duration can be reduced in the higher possible proportion while still getting an attractive bonus rate for subcontractors as a reward for adapting to the Critical Chain Methodology.

3.5 Project and Feeding Buffers sizing

<u>Project Buffer</u>

Under the original concept, the new project duration after applying CCPM is being measured as the time for executing the project (reduced) plus the project buffer, the project is expected to finish earlier than the CPM schedule. Figure 3 schematizes the effect of reducing the activities duration and inserting the project buffer over the total project duration as it has been conceived. As shown in Figure 3, the overall project duration is reduced, from the original duration PDO to the reduced duration PDR. In this research, the contract project duration is defined as the original duration PDO. therefore it is possible to consider the time between the PDR and PDO as the project buffer. By doing so, the basic CCPM concept of getting the project finished earlier is automatically discarded and the latest time would be the original project duration.

<u>Feeding Buffers</u>

This framework employs the same amount of time that is reduced in the activities of non-critical chains into feeding buffer. This approach considers that the feeding buffer to be allocated should be sized the same as the amount of time reduced in the non-critical chains.

3.6 Bonus Component 2

This bonus component is fed from the savings arising from the indirect cost that occurs when the project duration is reduced. Though the general contractor usually might be unlikely to share the indirect cost saving with subcontractors. However, this type of bonus would present a strong incentive to subcontractors to work as a group. Because it is not possible to know the real project duration in advance, this framework proposes to include this bonus component as an addition to the subcontract rules, under the statement that its payment will depend on how much time earlier the project is actually completed. If the project duration is actually reduced, the amount that will be saved for variable indirect cost concept at the end of the project can be expressed as:

$$B' = VIC \times (PD_O - PD_A) \tag{3}$$

Where:

B' = Bonus component 2 ($)

PD_A = Actual project duration (time units)

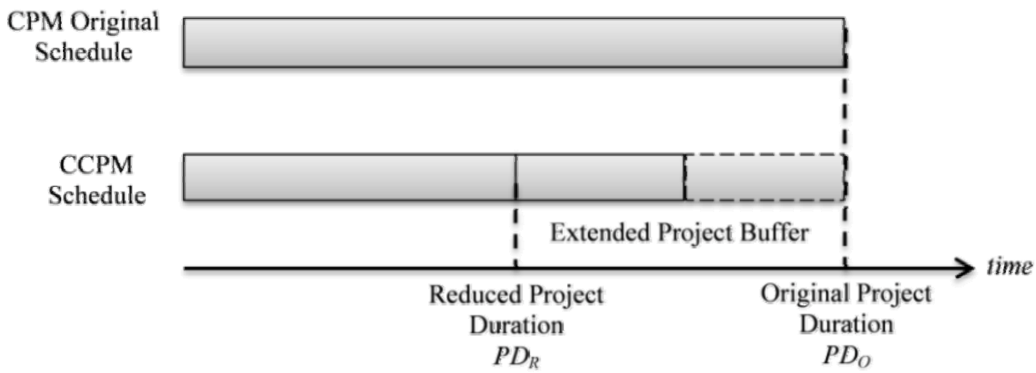

Figure 4: Project Duration Reduction with extended project buffer

3.7 Scheduling process

The scheduling process for this framework takes as a basis the CPM schedule that was defined in the pre-contractual stage, and is basically the same as proposed by Goldratt (1997), which consists of the following steps:

1. Reduce durations of activities in the schedule.
2. Resolve resource contentions.
3. Schedule activities to start as late as possible.
4. Identify the critical chain.
5. Insert project and feeding buffers.

The difference lies on two factors: first, the proportion of the reductions (step 1), which is a result of the time-cost trade-off explained previously for each subcontract. And second, step 2 can be omitted since the works will be subcontracted to different companies, so each of them will have their own resources. Furthermore, the general contractor must require to subcontractors to level their own resources in order to avoid any conflicts. And last but not least, it is important to remind that start dates are approximate, since it depends on predecessors real finish date. The implementation of the resource buffers should be stated under contractual terms, i.e. it should be clarified to subcontractors that they must be willing to start earlier, as long as they are warned in advance when the predecessors are about to finish. In this way, the efforts done when reducing durations are not wasted because the subsequent resource is not ready to start.

4. CONCLUSIONS

The proposed framework reduces the existing gap between the theoretical model and its practical use in construction project management by encouraging subcontractors to embrace the methodology and finish their assignments as soon as possible through the offer of bonuses. Even though it might seem that motivating subcontractors by the means of money goes against and modifies the critical chain original precepts, the bonus system presented herein should be as the complement to the existing parameters, that emerged due to the nature of the construction business. It is believed that the flexibility of this approach will enable the general contractor to adjust it to its own real situation and environment, hence giving the opportunity to implement it without struggling with the usual resistance.

This research assumes the interaction between bonus rate and percentage of reduction as a linear distribution and inversely proportional relationship. In the future, the research considering a discrete distribution, based on a more complex –and perhaps more realistic-relationship between the time and cost involved.

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CONSTRUCTION MANAGEMENT ON SITE: REQUIREMENTS FOR A LESSONS-LEARNED SYSTEM

Ximena Ferrada
Pontificia Universidad Católica de Chile, Santiago, Chile, xferrada@ing.puc.cl

Marcos Sepúlveda
Pontificia Universidad Católica de Chile, Santiago, Chile, marcos@ing.puc.cl

Alfredo Serpell
Pontificia Universidad Católica de Chile, Santiago, Chile, aserpell@ing.puc.cl

Abstract

Construction is a knowledge-intensive industry in which knowledge is mostly generated in the projects that each company performs. A problem arising is that many of these companies do not have a structured system to capture lessons learned on site, thus affecting organization improvement. Then, it becomes handy to have a system to identify, acquire, process, transfer and reuse experiences, whether they are the product of success or failure. The implementation of such a system would help companies to improve the performance of projects and therefore, of the organization as a whole. The objective of this study is to develop a lessons-learned system to improve the construction management process through the use of the information and knowledge generated in projects developed by a construction company. To reach this objective, a research methodology based on case studies has been applied, where semi-structured interviews, direct observation and review of documentation have been conducted in three construction companies with the purpose of understanding how construction companies manage construction on site, the associated knowledge flows and the main features of the context in which they work, in order to develop a lessons-learned system that fits these features.

This article presents the main results of the interviews with particular emphasis on the most relevant aspects related to having a lessons-learned system on site, presenting also an initial proposal about how such a system should be. Main conclusions are that none of the three companies have a lesson-learned system for construction management. Also, they recognize the convenience of the system specially because they do not carry out a systematic and structure use of the knowledge generated on site.

Keywords: construction management, lessons learned system, knowledge management.

1. INTRODUCTION

The construction industry has problems managing the information associated with the production stage of a project. Much information about previous projects is not reused, since there are not adequate mechanisms for their storage (Cooper et al., 2005). Some authors suggest that part of the knowledge generated within each project is finally stored in reports that very few read, or is lost because the people involved are moved to a new project, leave the company or retire (Kivrak et al 2008) (Anumba et al., 2005). This situation will eventually affect the performance of the company because the reuse of information and knowledge could reduce the time and cost to resolve problems and improve the quality of the solutions during the construction phase of a project (Lin et al, 2006). In fact, Krogh (2002) cited by Loforte (2009) indicated that project performance can be improved when people communicate and share best practices, lessons learned, experiences, insights, as well as common and uncommon sense.

In this regard, it is considered that knowledge management, when properly applied, allows a company to transfer knowledge between their projects, creating synergy within the organization, and learning from the mistakes and successes of others (Ferrada and Serpell, 2009). On this respect, Massmann et al (2008) indicate that in Chilean construction companies there is not a proper processing of the acquired knowledge for further dissemination into the company. Similarly, Ferrada (2011) verified the little usage of experience in the studied companies. In fact, no company had a knowledge management system itself, but only isolated actions of little diffusion. Then, it becomes handy to have a system to identify, acquire, process, transfer and reuse experiences, whether they are the product of success or failure. This article presents the main results of a study on the most relevant aspects related to having a lessons-learned system on site, presenting also an initial proposal about how such a system should be.

2. LESSONS LEARNED

Lesson learned (LL) is any experience or positive or negative perceptions that may be used to improve the performance of the organization in the future (del Moral et al, 2007). They can be seen as elements of experiential or tacit knowledge that have been rationalized and saved for future use, where the main idea is to encourage good practices to repeat successes and avoid past mistakes (Cheah et al, 2011). Snider et al. (2002) define a LL system as the activities, people, and products that support the recording, collection, and dissemination of lessons learned in organizations. The goal of LL systems is to capture and provide lessons that can benefit employees who encounter situations that closely resemble a previous experience in a similar situation (Weber at al., 2001). As LLs are captured from experience, the content of the LL should ideally be real or authentic. However, for the sake of privacy, the details of LLs may sometimes be intentionally modified without detriment to the integrity of the knowledge.

Kartam (1996) identified three major components of a lesson learned system (1) a set of attributes to sufficiently describe and explain the lesson itself, such as a lesson title, a description of the problem or situation, a description of the solution or method, additional comments and perhaps a relevant sketch or reference to other documents, (2) information regarding the source and context from which the lesson is collected, and (3) the means for classifying the lesson in a manner that allows fast and clear retrieval by multiple parameters. Soibelman et al. (2003) include some indexing items to define the context information for a design review lesson learned system, such as project type, client, location, and discipline. Also, to describe the effects of the new lesson, three description fields are identified: the reason to submit a new lesson (error, omission or coordination), the topic of the submitted lesson, and a definition of the expected effects.

Because LL systems include both best practices and mistakes or failures occurred in the firm, they are a great source of learning. Learning can be of two types: (1) single-loop learning is the acquisition of new behavioral capacities framed within existing insights, and (2) double loop learning, which occurs when organizations acquire behaviors capacities that differ fundamentally from existing insights (Liao et al, 2008). The study of failures, which are generally regarded as conflicting issues, leads to a double loop learning cycle, which encourages deep level reflection (Lo and Fong, 2010). Organizations including construction companies require double loop learning focused on the root causes of errors, which is an important issue in the construction industry (Lo and Fong, 2010).

According to Caldas et al. (2009), the lessons learned process includes three key steps: collection, analysis, and implementation. These authors indicated that collection is the gathering of knowledge and experiences from individuals in the organization. After lessons are collected, they must be analyzed and validated before they are disseminated through the organization. Last, the lesson is implemented in a way that can take many forms, ranging from publication of lessons in an electronic database to the changing of practices and procedures to reflect lessons learned. The least successful aspect of learning is the transfer of LL within an organization, particularly from the project team to the organization. Lack of employees' time and lack of management support are the leading reasons for LL not being undertaken as well as lack of incentives, resources or guidelines (Williams, 2008).

3. RESEARCH METHODOLOGY

The objective of this research is to develop a lesson-learned system to improve the construction management process through the use of the information and knowledge generated in projects developed by a construction firm. Then, a detailed analysis of the construction process, the knowledge required and feasible ways for their dissemination and use is required, so the system actually meets its objective. This research will focus on the on-site construction management process, as it is at this stage where the work is executed, being of the highest importance in the construction process (De Solminihac and Thenoux, 2008). This research has been structured in four stages: (1) Literature review, (2) Case studies, (3) Lessons- Learned System Design, and (4) Construction and Implementation of the Lessons- Learned System. The main objective of the literature review was to establish the context for the study, collecting relevant information about the central aspects of the research. Case studies were used to understand how construction companies carry out the construction management on site, their perception about how a LL system should be and the main features of the context where they work, in order to develop a LL system that meets these features. As the stated research question is: how should a lessons learned system be to be considered a tool to support construction management improvement?, the use of case studies was considered an appropriate research strategy since there is a relationship between the phenomenon under study and its context (Yin, 2003; Soetanto et al., 2007). Thus, a multiple case study research approach was adopted. Using a construction company as the unit of analysis, semi-structured interviews, direct observations, and review of documentation were conducted in three construction companies. This article presents the main research results obtained from the interviews conducted in stage 2.

4. RESEARCH RESULTS

The three researched construction companies have more than 20 years of experience. Two of them (companies A and B) are construction companies with ISO 9000 certifications, and the third one (company C) is a real estate and construction company without quality certification. In total, six professionals from company A, five from company B and five from company C were interviewed. Five Project Directors, eight Project Managers, two Quality Chief and one Operation Manager were interviewed.

First of all, a review of the companies' documentation was conducted. Starting with Firm A, it stores documentation about its finished projects in its Quality Department. Currently they are using a computer system to manage the documentation of the quality system, call ISONET. The technical problems are analyzed through non conformities or corrective actions, but most of the time these documents do not contain a detail solution of the problem. The information about the ongoing projects is stored on Dropbox folders and includes documents such as management reports, cost control reports, planning, innovation newsletters and labor reports. Company B is currently using MS SharePoint to manage the information of each project through a group of folders that contain project reports, achievement and difficulties reports, technical specifications and drawings, among others. In Company C each Project Director has his own structure to store the information about the projects he supervises. The information is stored in their computers and in paper. They considered that e-mail is an adequate way to send reports about problems on projects or to discuss about it.

We also visit some projects of each company. In the three organizations we could see that the communication is mostly done via radio, but people also use their personal cellphones to communicate on site with other project members. In the Technical Office people could access internet, but this access is only for the management team. Related to documentation, we find consistency with the information already collected. With this information the interviews were started. The next sections present the results related to how these companies manage their knowledge and their perceptions about how a LL system should be.

4.1 Knowledge management

To propose a lessons- learned system we need to understand how these companies currently manage their knowledge. Respondents were asked if they considered that in their companies they have all the required knowledge to perform the project. 50% of respondents said no, because not all organizational knowledge and information is easy to find, or because this knowledge was not recorded. The remaining 50% said yes, but emphasized that in general knowledge is on people's minds and not in the organization. Interviewees also indicated that what bothers them the most is the lack of documentation about repetitive project processes and subcontracts performance. Also they mentioned the need of lessons learned about the design and execution of the project. If they could have this information they could prevent the occurrence of mistakes in the projects. Also they mention as a very important issue the lack of contact between professionals of the same company to learn more about their experience on the projects they manage, even though company B has meetings on a regular basis.

Related to the information stored in the companies, two of them keep their knowledge through the organization's quality system, in procedures and corrective actions, among others. The content of these documents is not necessarily as detailed as it is needed in order to become a useful lesson learned, because most of the important details remain in the minds of the people involved in the solution development. The third company mainly stored information on a personal level, not through a standardized organizational system. Each Manager decide what information store and under what format. About the main constraints to acquire and store knowledge, respondents indicated that the main constraint is the lack of time during projects execution. Also, people indicated that they do not store knowledge because in organizational procedures it is not clearly defined what information or knowledge they need to save, with what format or where it must be stored. Some respondents also indicated that it is a cultural issue, that is, people are not familiar with the importance of stored knowledge. Finally, some interviewees indicate that no knowledge is saved because often they are considered obvious things that everyone should know.

4.2 Lessons learned system characteristics

The second section of the interview analyzes the perceptions of the respondent related to how they think a lesson learned system should be. Regarding the type of lessons learned that should be saved in the companies, the most frequently repeated responses pointed to save the strengths and weaknesses of each project, followed by information on constructive solutions, and new technologies or products. Also, respondents indicated the need to store knowledge about how to structure the site logistics, production statistics and administrative issues that people need to know in order to properly manage the project.

Interviewees indicated that a lesson-learned system must explain the problem and its solution. Also, it must have the name of the author of the LL and who approved it, and the main data about the project, such as geographic location and duration, among others. All respondents agreed that these lessons should be something simple, pointing directly to the relevant aspects of the problems or the situation under analysis. For example, some respondents indicated that they might have a set of frequently asked questions by trade, or a place to leave short hints on certain issues, as a way to transfer people's experience. Everyone thinks that a lesson learned system would help them in the management on site, as they could save time resolving problems or preventing the occurrence of mistakes if lessons are reviewed before performing certain critical activities. Despite this, none of the three companies formally documented lessons learned.

About the process to collect these lessons, more than fifty percent of respondents indicated that it should be the quality team who should collect lessons learned. They justified this answer indicating that the quality team seeks to improve the quality of the company processes to achieve a final product that meets the required standards, hence; their work has affinity with the objectives that can be achieved with a knowledge management system. 20% percent of the respondents indicated that the Project Manager should be responsible of the collection of LL since he is the one who knows best what is happening in his project and could be able to identify valuable lessons. Some respondents indicate that the collection of lesson learned should be the task of the Technical Office, as all the important information concerning the project passes through them. Respondents considered that it would be appropriate that these lessons will be collected during project team meetings (56,3%), so as to have a complete picture of the situation under analysis. Other respondents indicate that once a project ends, it could be possible to get the most relevant lesson learned of the whole project. Other interviewees said that ideally the lesson learned must be saved immediately in an information system. They also mentioned that it is important to use a standard format in the company to gather this information.

About the validation of lessons learned, 43,8% of respondents considered that the Project Manager should be responsible of this task. 18,8% of respondents considered that this should be done in project team meetings and another 18,8% think that it should be the quality department or the management of the company who must validate these lessons. 12,5% of respondents indicated that the validation should be done by someone skilled in the subject that is being stored. The remaining respondents indicated that the validation must have the same chain of approbation of the quality system.

Related to the dissemination of the lessons, 68,8% of respondents believe that this should be done through newsletters or email within the organization. 12,5% of respondents indicated that each person should be responsible for knowing the lessons learned that are stored in the system. Interviewees also noted that another good way to spread the learned lessons in projects are the meetings among professionals performed by some of the companies (18,7%). All respondents indicated that a lesson-learned system must have access through the internet or intranet, so people can access it easily and anywhere. Interviewees also indicate that the system should be simple, allowing a quick search of the required information. Related to factors that may limit their use in the field, 37,5% of respondents indicated that they don't see factors that limit their use in the field, while 18,8% indicated as an important factor the lack of time, especially to upload information. Other factors relate to the fact that in general, people want to keep their current comfort state and do not want to change. Also, some people prefer to maintain direct contact with their colleagues to get the necessary information. Regarding the use of mobile technology on the field, 87,5% of respondents believe that it would facilitate the use of a lessons-learned system, especially to search and get information. The remaining 12,5% of respondents considered that mobile technologies are not necessary to perform well the job.

5. PRELIMINARY LESSON LEARNED SYSTEM PROPOSAL

Based on the information previously presented, a preliminary proposal of a lesson-learned system for construction management on site is introduced. Currently this proposal is being validated with construction companies. Once this validation ends it could be possible to start with the design and construction of a system's prototype. The proposal includes the system itself and the process required to acquire, validate, store and disseminate the lessons learned through the organization.

Clearly, the most difficult task is getting people to actually document their experiences. For this is essential that top management defines the policies to manage organizational knowledge. It is proposed that Projects Directors or the Operation Manager define lessons learned that need to be acquired from each project. This people have a vast knowledge of the company and of the projects they developed, so that they could identify what knowledge could be useful for the company and needs to be saved. Once these guidelines have been delivered to the Project Manager, the collection must be configured by the Technical Office with the support of the Quality Department. This must be a team effort among the ones that have all the information about what happens on site (Technical Office) and the ones with more experience in collect information (Quality Department). The initial collection can be done in weekly meetings or by interviews with the people involved in the lesson. A standard format that indicates all the items that need to be completed can support this task. The validation of the lessons learned must be done by the Project Manager, because he has the experience to analyze if the content of the lesson is an adequate representation of the described situation. If the lesson is about a very specific topic, this validation must be complemented with the validation from an expert on the topic. The dissemination of lessons learned must be done through periodical newsletters. The Quality Department must be responsible of sending this information via e-mail to all the professionals of the company.

Based on comments from respondents, the interaction face to face is very important. They like to ask people about relevant issues or tell them about their experiences. However, because their companies are growing and professionals are located throughout the country, the interaction is increasingly difficult. Then it is proposed that the lesson- learned system includes two elements: (1) a lessons- learned database and (2) an organizational microblog, as shown in Figure 1. System users may perform in five different roles: System Manager, Lessons creator, Approver and Consultant. How each of these roles interacts with the system is shown in Figure 2.

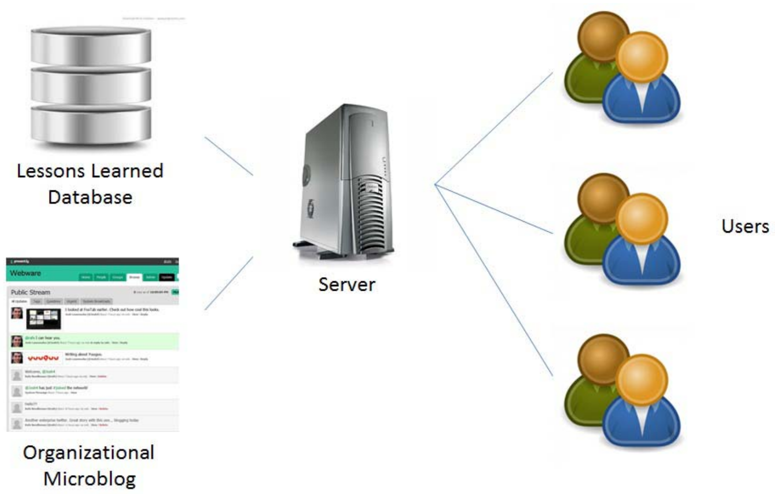

Figure 1: Proposed lessons-learned system

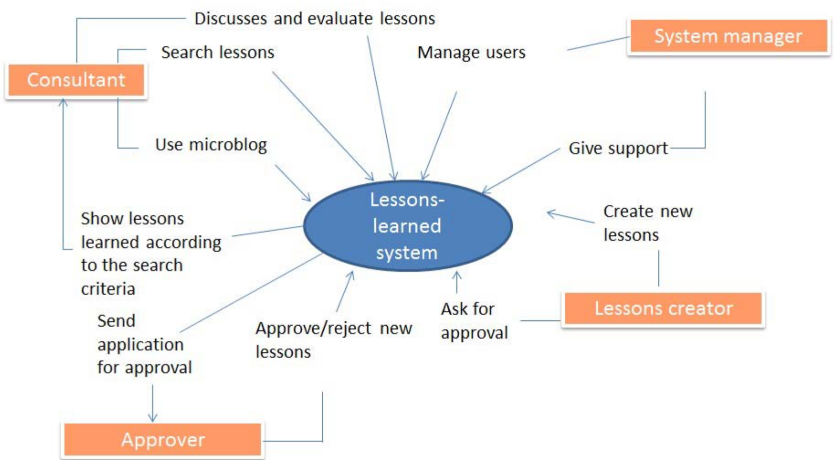

Figure 2: Context diagram

The main functional and non-functional requirements for the system are define in Table 1. Based on the results of the interviews and the analysis of the knowledge flows in the construction management on site, we proposed that the content of the lessons learned include the elements defined in Table 2. Clearly this is a very general description of the features of system which is now under development of its detail design, and under the validation of the participating construction companies.

Table 1: Main system requirements

Functional requirements	Non-functional requirements
Lessons Creator • The system must provide a "New lesson learned" form to create a new document. • The system must save the data included in the lessons. • The system must allow uploading files. **Lessons Creator/Approver** • The system must include an automatic flow of internal approval of new lessons. • The lessons must be evaluated by users. • The system must allow searching by keywords and predefined filters. **Consultant** • The system should display the search results whenever the user requires. • The system should allow download the lesson learned and the documents attach to it. • The system must be accessible from the internet, requiring login and password. • The system will include an organizational microblog for use by registered users only. • The system must be accessible from a mobile device like a Smartphone or tablet.	**Lessons Creator** • Users should be able to upload files to the system in Word or PDF format. • The form "New lesson learned" should be configurable by the company, allowing the configuration of the field: Subject / Area of the lesson. **Consultant** • Users should be able to export the lessons in PDF format. • The result of these consultations and the deployment of data must be in an estimated time from 5 to 15 seconds. **All users** • The system must be able to be seen correctly when using the most common browsers. • The system should be hosted on a server that allows access it from the Web. • The system should have a friendly interface.

6. CONCLUSIONS

Even though knowledge management is an organizational topic with lots of related research efforts, it is possible to conclude that their actual implementation effort is very small. The studied Chilean construction companies do not have a knowledge management structure and their efforts on this area are very limited, even though they recognize their relevance to achieve final project goals. The proposed LL system includes not just a general analysis of the technical requirements, but also a proposal about the process to acquire, store and disseminate the lessons within the organization. It is expected that a system like this, could really improve the construction management's performance on site. Next steps on the research include the validation of this system features' proposal and the design and construction of a system prototype. This prototype system will be implemented in one of the participant construction companies to evaluate its performance.

Table 2: Lesson-Learned Content

<table>
<tr><th colspan="7">Lesson-Learned Content</th></tr>
<tr><th colspan="5">Generic Attributes</th><th colspan="2">Context attributes</th></tr>
<tr><td>Title</td><td colspan="3">Abstract</td><td rowspan="2">Approver</td><td>Project duration</td><td>Geographic location</td></tr>
<tr><td>Creation date</td><td colspan="3">Author</td><td>Project name</td><td>Disciplines involved</td></tr>
<tr><th colspan="7">Lessons Attributes</th></tr>
<tr><td colspan="3">Lesson origin (best practice or error/omission)</td><td colspan="3">Description:
• Is it a routine situation?
• At what stage of the project this situation took place?</td><td>Brief explanation of the situation</td></tr>
<tr><td colspan="7">Lesson area: project design, technical and construction methods, quality management, new technologies and products, regulations, suppliers and subcontractors, administrative processes, security and risk prevention, project planning and strategy.</td></tr>
<tr><td colspan="5">Criteria to apply what was learned</td><td colspan="2">Explanation of what was learned</td></tr>
<tr><td colspan="2">People who participated in the solution</td><td colspan="2">Time it took to apply the solution</td><td colspan="2">Expected effect of applying the lesson: cost, time, quality, scope</td><td>Complementary documentation</td></tr>
</table>

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CONSTRUCTION METHODS SELECTION: A KNOWLEDGE-BASED SYSTEM

Ximena Ferrada
Pontificia Universidad Católica de Chile, Santiago, Chile, xferrada@ing.puc.cl

Alfredo Serpell
Pontificia Universidad Católica de Chile, Santiago, Chile, aserpell@ing.puc.

Abstract

The appropriate selection of construction methods to be used during the execution of a construction project is a decisive factor for its suitable development and for the attainment of its requirements. Since construction is a knowledge-intensive activity, this paper proposes a knowledge management approach that will enable the intelligent use of corporate experience and information, and help to improve the selection of construction methods for a project. Then a knowledge-based system to support this decision-making process is proposed and described. To define and design the system, semi-structured interviews were conducted within three construction companies with the purpose of studying the way that the methods' selection process is carried out in practice and the knowledge associated with it. Additionally, the information so obtained permitted the identification of existing knowledge gaps in the process. A prototype of a Construction Methods Knowledge System (CMKS) was developed and then validated with construction industry professionals. The validation showed that the prototype adequately responded to the needs of construction companies. It was considered useful and applicable to construction projects. As a conclusion, the CMKS was perceived as a valuable tool for construction methods' selection, by helping companies to generate a corporate memory on this issue, reducing the reliance on individual knowledge and also, the subjectivity of the decision-making process. Therefore, the system can be used to improve the final methods' selection and reduce the chances of a bad decision in this way. The described benefits as provided by the system favor a better performance of construction projects.

Keywords: construction methods, knowledge-based system, prototype, knowledge management, methods selection.

1. INTRODUCTION

Many studies have been conducted to understand further the reality of construction projects, which have identified several factors that affect the productivity and efficiency of these projects, being one of them, the selection of construction methods (Thomas et al., 1990). This selection process is mentioned also as one of the five potential areas of productivity loss according to the

ECI (European Construction Institute) (1994), while the inadequate selection of construction methods is cited as one of the major causes of delays that are the responsibility of the contractor (McCaffer et al., 1997). The selection of construction methods is a decisional process required for the proper development of a construction project, because its inadequate execution can cause significant losses of productivity on a construction site (Serpell, 2002). In many cases, this decision process is conducted without the care required, with an insufficient analysis of available alternatives (Basha et al., 1991 cited by Youssef et al, 2005). One of the factors that influence this situation is the difficulty presented by construction companies to manage the information associated with the construction phase of a project, coupled with the fact that much information about previous projects is not reused because there are no appropriate mechanisms for their storage (Cooper et al., 2005). Furthermore, the knowledge created on the field is not usually shared, which tends to produce its loss (Al-Ghassani et al., 2006). This situation eventually affects decision-making, where good decisions are the result of the careful management and analysis of the available project information and knowledge (Sommerville and Craig, 2006).

This article presents the main stages of the development of a knowledge management system for the selection of construction methods. The objective of this system is to support the decision making for the correct selection of the construction methods in construction projects.

2. CONSTRUCTION METHODS

Construction methods are the means used to transform resources into constructed products (Tatum, 1988). Therefore, programming and management techniques are of little value for a project if construction methods to be used are not the most optimal in terms of cost or are not safe to run (Illingworth, 1993). The selection of construction methods affects not only the selection of the activities and their work sequence, but also its duration (Fisher and Aalami, 1996). This selection process corresponds to a decision-making problem, which is based upon several criteria, considers multiple objectives such as cost, time, risk, and safety, among others. In cases like this, when a decision problem have at least two conflicting criteria and at least two criteria of solution, the problem is considered a multi-criteria decision analysis (Hurtado and Bruno, 2005). Related to the application of knowledge management in the selection of construction methods, Ferrada and Serpell (2010) indicate that construction companies rely on individual knowledge to carry out this process. This implies that there is not an organizational learning process to acquire relevant knowledge related to construction methods, in order to avoid repeating the same mistakes.

3. KNOWLEDGE MANAGEMENT IN THE CONSTRUCTION INDUSTRY

Different studies have tried to understand how knowledge management has been implemented in construction companies and also the perceptions of people about this topic (Carrillo et al., 2004, Carrillo and Chinowsky, 2006, and Forcada et al. 2013). Learning has also undergone some studies such as those of Fu et al. (2006) and Chinowsky and Carrillo (2007). Other lines of research have focused on the development of methodologies for the capture and reuse of the knowledge created in projects (Tan et al., 2007; Kivrak et al., 2008). In the area of construction methods' selection, studies have mainly been associated with the development of expert systems such as Alkass and Harris (1988), Hanna et al (1992) and Russell and Al-Hammad (1993). Clearly this is only a brief mention of the efforts made in this area, but it shows the relevance of this research topic in the construction industry.

4. KNOWLEDGE MANAGEMENT SYSTEM FOR THE SELECTION OF CONSTRUCTION METHODS

The study was based on case studies, involving three Chilean construction companies, each with at least 20 years of experience and ISO 9000 certifications. Two of them specialize primarily in the development of civil, industrial and building work, while the third company is mainly engaged in performing residential, institutional, commercial, and tall buildings projects. Data collection was conducted through semi-structured interviews.

Results of the study of cases showed that the selection of construction methods is largely based on the previous experience of professionals. Is a process characterized by the complexity of the analysis, the high dependence on individual experience and teamwork, and the need of expert knowledge for decision making. Senior management of construction companies recognizes the need for a structured system for their knowledge management. In addition, knowledge acquisition is not part of any established process, so people have no obligation or incentive to do it.

An important part of this research is related to the identification of knowledge gaps in the construction methods selection process. Results from case studies indicate that the main gaps in this regard, are in the activities "search construction methods" and "application of decision criteria." Regarding the search interviewees did indicate they have a very limited time for this activity and that this activity is largely based on individual knowledge, since lessons learned are not stored and there aren't procedures for an effective knowledge management. Related to the application of the decision criteria, it currently depends heavily on the decision maker intuition, and then they are not comparable across projects. It becomes necessary then, to reduce the subjectivity and variability of the decision making process by doing the most important decision criteria explicit for selecting construction methods. From the results of the interviews, it was possible to identify key criteria to use in the selection of construction methods, including project duration and cost, product characteristics, construction method characteristics, and environmental characteristics. The criterion "product characteristics" has two sub-criteria: building volume and quality requirements, while the criterion "characteristics of the construction method" has five sub-criteria: familiarity with the construction method, health and safety, level of automation of the method, level of interference with other operations and availability of the method.

Finally, the criterion "environmental characteristics" has four sub-criteria: location and access, climate, obstacles / topography and available space. These criteria were validated with experts of the studied companies and were used in the development of the knowledge system.

The analysis above enabled the definition of some features for the system. The information and knowledge gained would be stored in organizational databases linked with a knowledge portal called Construction Methods Knowledge System (SCMC in its Spanish acronym). In this case, a knowledge portal implemented on a web platform for easy access from any location, and with the capacity of storing in databases all the information associated with construction methods is proposed. Furthermore, a decision making support system for the selection of construction methods would be accessible from this portal.

The information was stored in the form of construction method's sheets. The content of each sheet is based on the knowledge linked to the selection of construction methods, as identified during the study of cases. The information included on a construction method's sheet is shown in Table 1.

Table 1: Construction method's sheet

<table>
<tr><th colspan="10">Construction method's sheet</th></tr>
<tr><td>Discipline</td><td colspan="3"></td><td rowspan="3">Code</td><td colspan="5" rowspan="3">Related to other sheets:</td></tr>
<tr><td>Operation</td><td colspan="3"></td></tr>
<tr><td>Construction method</td><td colspan="3"></td></tr>
<tr><td>Degree of automation</td><td>1-5 scale</td><td>Yield</td><td></td><td>Cost</td><td colspan="2"></td><td colspan="2">Risk level</td><td>1-5 scale</td></tr>
<tr><td colspan="4">Used in the company: Yes/No</td><td colspan="5">Degree of interference with other operations</td><td>1-5 scale</td></tr>
<tr><td colspan="4">Restrictions: description of restrictions</td><td colspan="6">Restriction type:</td></tr>
<tr><td colspan="4" rowspan="3"></td><td colspan="2">Space</td><td colspan="2">Security</td><td colspan="2">Competencies</td></tr>
<tr><td colspan="2">Inspections/permits</td><td colspan="2">Materials</td><td colspan="2">Weather</td></tr>
<tr><td colspan="2">Topographic</td><td colspan="2">Machinery</td><td colspan="2"></td></tr>
<tr><td colspan="4">Type of project were it has been used</td><td colspan="6">Project names</td></tr>
<tr><td colspan="4">Labor requirements</td><td colspan="6">Materials requirements</td></tr>
<tr><td colspan="4">Equipment and machinery requirements</td><td colspan="6">Temporary requirements</td></tr>
<tr><td colspan="4">Fundamental activities included in the method</td><td colspan="6">Work process</td></tr>
<tr><td colspan="4">Subcontracts that can perform the method</td><td colspan="6">Experts on the method</td></tr>
<tr><td colspan="10">Lessons-learned associated</td></tr>
</table>

5. PROTOTYPE DESIGN AND CONSTRUCTION

5.1 System requirements

Based on the requirements defined the selection of the computer applications that compose the SCMC was performed. This study began with the search of computer programs available in the market for each of the two major components of the SCMC, (1) the knowledge portal and (2) the system to support decision making. The objective of this task was to determine if appropriate software was available in the market, in order to reduce the programming work or if it was necessary, to start all programming from scratch. For the knowledge portal the best option was to design and construct it from scratch so that specific needs of construction companies would be met. For the decision support system developing software was the least suitable alternative, because existing commercial software offered what was exactly needed. The online system Make it Rational™ was selected for this purpose, because it is easy to use and allows access through the web. This software is based on the Analytic Hierarchy Process (AHP), a widely applied multi-attribute decision making method (Fülöp, 2005). The method helps in converting subjective assessments about relative importance of items, to a set of overall scores or weights (Fülöp, 2005).

5.2. System architecture

The database system works on Microsoft SQL Server™, which is a database management system based on the relational model. This database has a structure defined by the data included in the construction methods' sheets. This allows construction companies to generate a construction method's corporate memory in which they may rely on when they need to select construction methods for a particular project. To define the system architecture, the software architecture pattern Model-View-Controller (MVC) was used. This pattern allowed separating the data from an application, the user interface and the business logic into three distinct components (Hankness, 2009). The graphic design of the interfaces (colors, organization of content, fonts, etc.) was made from a free to use HTML template selected for this purpose which works within the MVC application.

5.3. Construction Methods Knowledge System (SCMC)

Access to the SCMC is through the internet, with a login and password. After the authentication, the user accesses the system according to one of the following roles: User Manager, Sheets Manager or Consultant. The interaction of the users with the system is defined in the Context Diagram of Figure 1. To illustrate how the system works, suppose a Project Manager that has a Sheets Manager role. If this user wants to enter information about a new construction method, it will face a view as presented in Figure 2, where he must enter at least the mandatory data: method's name, discipline, type of operation, risk level, yield, cost, core activities and whether the method has been used previously in the company. Once the Sheets Manager saves the new file, the system shows the new sheet with the options to edit, delete, export, or view previous versions of the sheet (Figure 3).

If the user (Sheets Manager or Consultant) needs to search for construction methods for a project, he/she could search the database. This search can be performed in three ways: (1) using a quick search by using keywords, (2) in a catalog of methods, which allows searching by the initial letter of the name of the method, or (3) through an advanced search, which allows to search using filters such as method's name, discipline and type of operation. In this case the system searches all the sheets on the database according to the fields defined by the user and it presents the results that match the search parameters. Once the results are received, the full version of the sheets can be accessed for review. Then the feasible alternatives to perform the operation under consideration can be defined. To carry out the final selection of the construction method it is necessary to evaluate these alternatives in terms of different decision criteria. In order to make this part of the process more objective, the SCMC includes a system to support decision-making whose access link is shown on the right side of the screen (Figure 3).

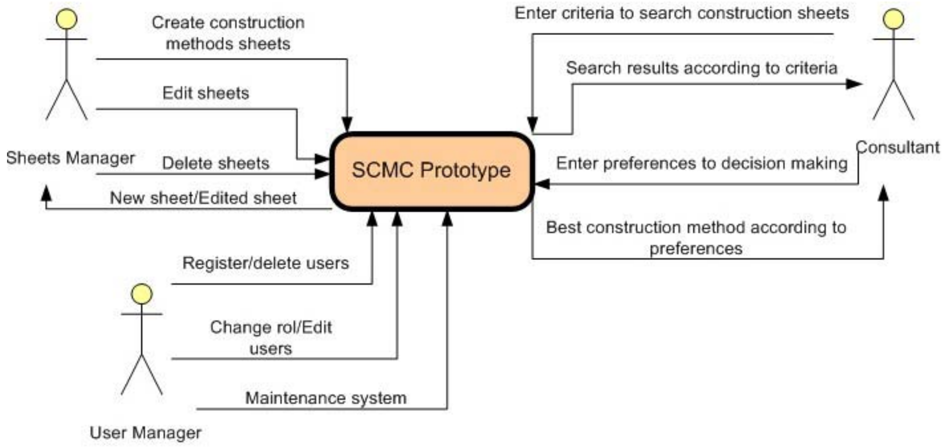

Figure 1: Context diagram

Figure 2: Sheet creation

Figure 3: Sheet completed

When accessing the latter application, a file named “Selection of construction methods” should be open, which contains the hierarchical structure of decision criteria obtained from the study of cases. After opening the file, the user is faced with a set of windows: a) ALTERNATIVES, b) CRITERIA, c) EVALUATION, d) RESULTS, and e) REPORT. The first window allows defining the alternatives for the decision process. With this information the user enters the CRITERIA window, which contains the decision criteria previously defined and the description of each one. The third window allows the input of user’s preferences, as described in the AHP methodology. For this, three kinds of comparisons are necessary. First, for each sub-criterion or criteria without subdivision, different alternatives are compared in pairs (Figure 4) and in each of these cases the user is asked about his/her preference which is input by marking the triangle containing the number that better represents it, ranging from 1 to 9. Then, for each criterion with division, the user must assess the importance of each sub-criterion with respect to the central criterion, also in pairs. Finally, main criteria should be compared among them to achieve the selection of a construction method. Once all comparisons are made, it is possible to access the "RESULTS" window. Here the system indicates what alternative is the best in terms of the user’s preferences. For example, Figure 5 shows a bar graph that shows the utility of each alternative. Finally, in the REPORT window, a report with the results can be automatically generated and then exported to several formats.

6. PROTOTYPE VALIDATION

During its development, the SCMC was presented three times to two experts on construction methods selection, each from a different construction company. The comments received were used to improve some aesthetic aspects and the interaction with the user. Since it was not possible to conduct a long-range validation test, i.e., the application of the system in a real work environment due to time restrictions, a final validation of the construction methods' selection system was carried out with a wider group of experts, with the goal of verifying the usefulness of the system and its practical applicability.

6.1 Validation interviews

The validation process included interviews with eleven construction professionals from six different companies, with experience in construction methods' selection. Two of these professionals had participated in the progress meetings of the SCMC, five had participated in cases' study, without any involvement in the development of the SCMC and four had been integrated into this final stage. These professionals work in the following roles: Technical Manager, Head of the Estimation Department, Project Manager and Head of Management and Innovation. All of them received a complete presentation of the SCMC and a brief interview with each professional was conducted in order to know their opinions about the prototype. The main results are presented below. The system was considered a useful tool for the selection of construction methods, because it helps to make more informed decisions and have all the information needed in just one place. With the same level of importance, people said that the system is a valuable mean to increase organizational knowledge, reducing dependence on individual knowledge. Also, the system was considered as a suitable tool for sharing that knowledge within the organization.

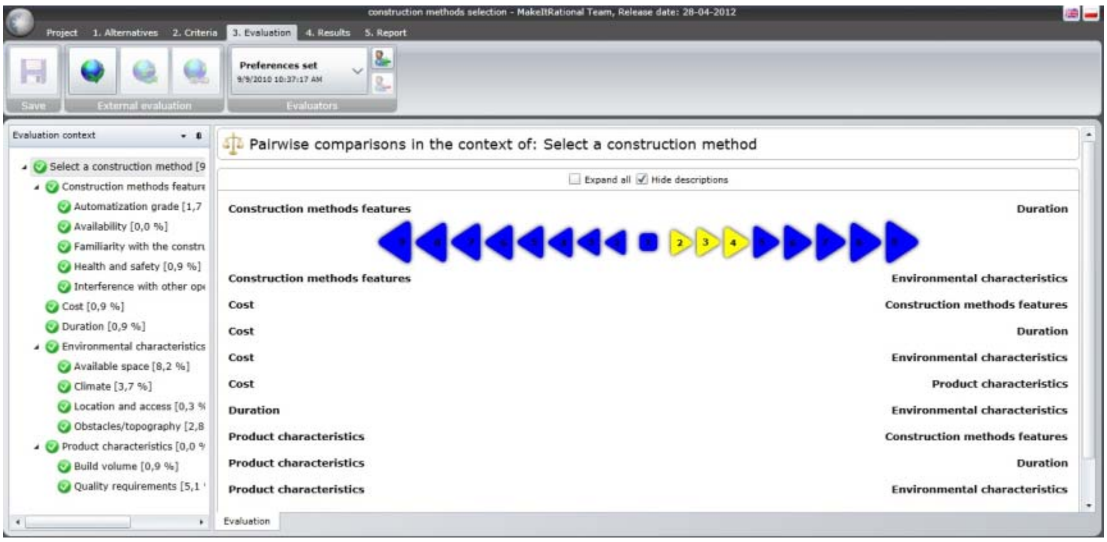

Figure 4: Input of user' preferences using Make it Rational

Figure 5: View of results in Make it Rational

In addition, respondents highlighted the time savings in the search for alternative construction methods and the possibility to store, organize and classify information regarding these issues, and considered it as a good guide for the decision-making process, decreasing the likelihood of making a wrong decision in this way. Likewise, they indicated that this system would help them to develop a knowledge oriented culture in the organization.

Ten of the eleven respondents would use the prototype in their daily work, and found it friendly and easy to use. Its main practical value was the increasing of their productivity by saving time in searching for alternative methods of construction and the easy access to information. They also indicated that this system would help their companies to introduce innovations within the organization and reduce costs and time in projects.

7. CONCLUSIONS

This paper has described the development of a knowledge management system for construction methods' selection process, and its main characteristics (SCMC). The SCMC contributes in the study and selection of the construction methods of a project, saving time and effort in the search. The system works as a support tool for operational decision making, helping to improve the quality of decisions related to the selection of construction methods and thereby, decreasing the chances of not meeting project goals like time, budget, or full customer satisfaction. Besides, the application of the system might reduce the impact of the departure of key employees from a company, since it enables the acquisition and storage of the knowledge generated in each project. Then it becomes an organizational asset and not just an individual asset.

The opinions given by respondents during the SCMC prototype's validation confirmed its contributions to construction companies: the availability of the information and knowledge stored; the improvement of the decision-making process; and its simplicity of use. These features make the system valuable and applicable in the day to day activities of a construction company. The application of this system on site in the future will help to completely validate its worth and improve its performance.

There still are plenty of opportunities to improve a construction project' performance, especially in knowledge-intensive processes such as the one approached in this research.

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UPBRELLA AND BIM: RETHINKING THE CONSTRUCTION PROCESS IN RESIDENTIAL CONSTRUCTION

Daniel Forgues
École de technologie supérieure, Montreal, Canada, daniel.forgues@etsmtl.ca

Dimitri Schmitz
University or Liege, Liege, Belgium, dimitri.schmitz@ulg.ac.be

Souha Tahrani
École de technologie supérieure, Montreal, Canada, souha.tahrani@gmail.com

Abstract

The problems of productivity, predictability and quality in design and delivery of the building product are well documented. Prefabrication, process reengineering and digitalization are proposed as potential solutions to address these issues. One issue that is rarely addressed, however, is the management of the changes required to move from existing to a new paradigm of practices. Organization of work in construction, as opposed to other industries, has barely evolved in the last centuries.

The research project studies the impact of the introduction of a new high-rise building construction system and BIM related technologies on the organization of work within a multi-residential project. The aim is to develop a concept of operation on how to reorganize work process within and between practices and trades. Ethnographic methods were used to identify issues regarding the management of information, the organization of work and the perceptions regarding BIM associated technologies and tools such as electronic tablets. Benchmarking and lean production tools such as value stream mapping were also utilized to identify problems of productivity and waste.

Waste related to poor management of workflows and information flow was a major issue and had a strong impact on productivity. Contractual context in which there are no incentives for professionals and trades to improve their overall performance (no share responsibilities and fragmented obligations) was identified as the principal obstacle to changes in existing practices. Traditional project management practices proved to be inefficient to compensate the lack of coordination and collaboration between the project stakeholders. However, even if the use of BIM proved to be impractical in this context, tablets were well received as a way to improve collaboration and coordination of the work. A concept of operation was derived from the lessons learned that will be validated in the next pilot project.

Keywords: construction system, BIM, change management, lean construction.

1. INTRODUCTION

The construction industry is a major component of the economy of many countries including Canada. However, construction continues to lag behind other industries, such as manufacturing, in terms of adopting information technologies (IT), which have brought major productivity improvements to other industries. The construction industry seems to follow changes from a distance. IT has been used as a support tool rather than a driver in the design and construction process. Furthermore, both IT and process have been treated as separate entities without any apparent links (Cooper et al. 2004).

This research belongs to a large ongoing research project that was initiated in fall 2010, and aimed at better understanding how information technologies have the potential to transform a construction project, in terms of processes and interactions between stakeholders, with the goal of addressing industry issues regarding productivity. Research findings of previous phases highlighted that technologies and tools related to building information modeling (BIM) are the most promising in terms of improving the productivity of the construction industry (Forgues et al. 2011). An experimental program has been developed to study BIM adoption within small and medium enterprises in the Canadian Architecture, Engineering and Construction (AEC) industry. Three pilot projects have been identified to cover different angles of BIM for improving productivity in construction. This paper presents preliminary results of one of these pilot projects, conducted in Quebec, which aimed on assessing how a new Building Construction System –called Upbrella – that offers a controlled and protected built environment, influence the organization of work in the construction of a new multi-residential building. The objectives were (1) to understand the challenges facing the implementation of a factory-like approach in a construction project, (2) to experiment BIM related technologies to facilitate the evolution of existing practices for a better control of the production process – these with the aim of developing a concept of operation for the next pilot project.

2. BIM, LEAN AND PRODUCTIVITY

Various reports have outlined the lack of productivity as a major issue of the construction industry. Two different initiatives aimed to solve this issue are creating fundamental changes in the planning and delivery of construction projects. The first is a transformative information technology – Building Information Modeling (BIM) –, and the second is a conceptual approach to project and construction management – Lean Construction.

Building Information Modeling (BIM) is about integrated technologies and sets of processes to produce, communicate, and analyze building models containing coordinated, consistent, computable information about a building project. The core principle of BIM is to create a shared, multi-disciplinary virtual model of a building that contains precise geometry and relevant data needed to support the design, fabrication, construction, and operational activities needed to build and manage the facility. The parametric information in the intelligent digital model can be used for a variety of purposes, including design decision-making, production of high-quality construction documents, simulation of building performance, cost estimating, construction planning, and even space management.

Research (Eastman et al. 2008) shows that the use of BIM during the construction processes was responsible for major reduction of request for information and change orders – which translated into gains in productivity. However, BIM is a disruptive technology, which means that the effective use of BIM requires to reconfigure and integrate work between specialties around the BIM enabled tools. Its biggest impact is on traditional project and construction management practices. BIM being a shared and integrated platform, it is quite difficult to divide work around activities and tasks. It is more question here of planning and managing workflows and dataflows.

Lean construction refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System to construction. Both focus on reduction of waste, increase of value to the customer, and continuous improvement. A core concept of Lean is the management of flow. Lean construction is therefore considered as a much better approach to manage the various uses of BIM than traditional project management tools.

2.1. The context of small and medium enterprises in Canada

The Canadian AEC industry is characterized by the vast amount of Small and medium enterprises (SME), which form its supply chain. These SMEs, working in various fields and disciplines, come together to create temporary project teams and form the backbone of the Canadian construction industry. In effect, of the 37,678 employers in this industry, 99.9% of those are considered SMEs (less than 500 employees) with the majority of firms (63.8%) counting less than 5 employees. While past research has set out to enquire and explain this phenomenon, noting the challenges and the benefits of such a reality, it remains that SMEs in the Canadian construction sector have to contend with increasing pressure from multiple sources, such as increasing global competition and internal economic pressures. In parallel, a recent study by Industry Canada has found that between 2002 and 2011, labor productivity for the Canadian construction sector has decreased 0.7% per year on average, while labor productivity for the Canadian Economy has increased 1.7% per year over the same period. Thus, SMEs in the Canadian construction industry are faced with multiple challenges that, if not properly addressed, can pose a serious threat to their existence. Therefore, there is a need for these SMEs to find ways to increase their productivity, offer value added services, and set themselves apart from the competition in order to strive and contribute to the Canadian economy.

3. THE UPBRELLA SYSTEM AND ITS POTENTIAL IMPACT IN CURRENT CONSTRUCTION PRACTICES

The system is a construction method specifically adapted to the construction of high-rise buildings in a controlled environment. The concept of Upbrella system revolves around the use of a roof which is at the same time independent, vertically mobile, mechanized, and supplied by various services (it is surrounded at its perimeter by panels of temporary protection and distribution system consisting of monorails). The roof is pitched and, as and when the construction progresses, various works are performed in stable conditions almost equivalent to conditions prevailing in a factory.

The roof is the attachment point and constructive central reference of the project. The mechanization of the assembly permits to gradually build the building and at a steady pace (which can be stopped or slowed down if necessary), in addition to providing a work environment within controlled and protected from the elements. On the other hand, building by "group of floors" frees floors built quickly and therefore, in the interests of the client, opens the possibility of progressive occupation of the premises if desired. It is also characterized by the absence of cranes, since all components are transported outside by a hoist (the carrier) – closed and secured for the duration of construction. The hoist is attached to one side of the building and consistently makes the shuttle between the transfer platform covered, at ground level, and the top of the building in which the work is conducted.

3.1 The Upbrella system and the context of residential construction

The main challenge in convincing the industry to adopt the system is to demonstrate the gains in productivity and cost reductions that it will permit to achieve. One approach is to use BIM 4D simulation to estimate the potential gains. This was realized in a previous research (Forgues, Velhinho, 2011) for a high-rise residential building. The goal was to convince a developer to use the system in a pilot project.

Since the enterprise did not succeed in convincing a developer to take this risk, it decided to start its own development and construction company, and to realize a first demonstration project. The project was included in our BIM experimental research program. While there are numerous case studies in the implementation of BIM or Lean Construction for commercial and institutional project, not much has been researched in the residential sector. The focus of these researches is mainly on improvement of building performance using BIM for design optimization. Our assumption was that, because this sector has a very low level of maturity in project and construction management practices, it would be easier in the new construction environment provided with the Upbrella system, to convince the various members of the construction team to try new approaches using BIM or Lean related technologies and processes.

4. THE RESEARCH DESIGN AND METHODOLOGY

The experimentation program was established in four steps:

Step 1. Benchmarking the project's current situation: This step aimed to identify issues and challenges related to the current practices concerning use of technologies, and organizational structure. Interviews have been conducted at the end of June 2012 with project stakeholders (client/system developer, project manager, general contractor, structural engineer), and were then combined with field observations to identify the problems that were faced during the construction phase, and to collect performance measurement that can be used to create value stream mapping to identify the project wastes. The analysis of collected data also helped the development of the current organization chart, the modeling of information flows, and workflow.

Step 2. Defining the desired solution based on project stakeholders' expectations: Interviews and observation analysis also allowed the definition of the action plan that can meet project stakeholders' expectations and goals.

Step 3. Determining and sorting requirements for an instrumentation of the new Construction Process: this step is mainly based on results issued from a focus group that included main key players at the project. The focus group aims to share the experience to define the requirements of the technologies to be tested in field, and to validate the findings of the analysis of step 1 and 2.

Step 4. Proposing the instrumentation and the concept of operations that will support the new construction process. BIM and ICT tools, selected according to the focus group results, will be experienced to identify advantages and limitations of each technology. The evaluation of the selected technologies will be based on an evaluation list, interviews, and filed observations. Feedbacks from users and observation interpretation could set the requirements of the new instrumentation, and help the identification of the concept of operations to be used in the future projects.

4.1 Measuring the productivity improvement for the project

The project is a six floor multi-residential building including 33 two bedrooms units. The construction is quite conventional with a steel structure and concrete floors for sound insulation.

Figure 1: The project

The plan was to build the first 4 floors using a conventional approach, and then use the Upbrella system for the two last floors. It was motivated by the fact that the financing of the system was still not secured at the start of construction. This was nonetheless an opportunity to facilitate the benchmarking of traditional versus the Upbrella enabled construction. Productivity measures derived from a Lean production control system were devised to track and compare performance. It was planned to compare 3 stages in the evolution of the construction process: the first two floors were planned to be built following traditional methods; from the lessons learned, a new organization of work inspired from Lean would be experimented for the construction of the two next floors; and then, applied in the construction of the two last floors using the Upbrella system.

The goal regarding BIM was to experiment (1) various BIM uses that are considered as having positive impacts on productivity, such as 3D visualization, clash detection and construction simulation; (2) enabling technologies such as interactive boards and tablets.

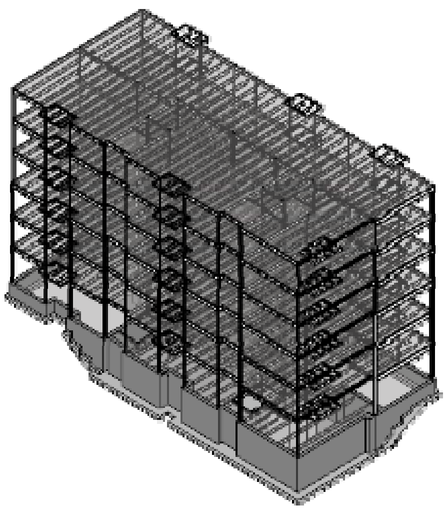
5. CHANGE ISSUES WITH PRACTICES IN THE RESIDENTIAL SECTOR

Since the enterprise did not have the in-house knowledge or expertise to conduct a construction project, it outsourced both the project/construction management and the design work. Therefore, the level of their power and influence on the design and management process was rather limited. Another issue was the cancellation of the loan for the Upbrella system which reduced drastically the supply chain incentives to experiment with new approaches or technology. We nonetheless analyzed problems and proposed solutions related to changes in existing practices from three dimensions: Technology, Process, and Organization (Staub-French and Khanzode, 2007).

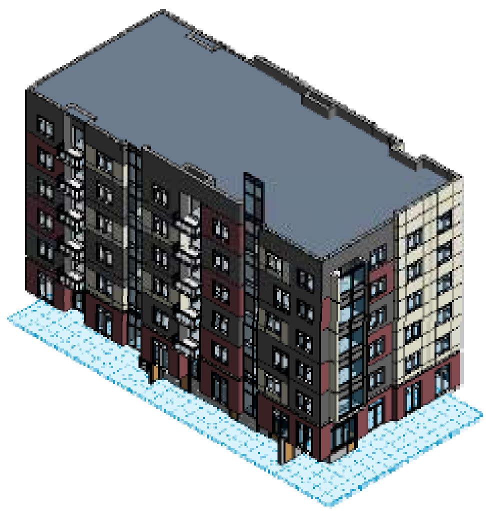
5.1 Technology

The team of design professionals, project/construction managers and sub-trades is representative of what is usually encountered in small and medium scale multi-residential projects. Their maturity level in the use of technology is very low and limited. Communication tools between the members of the project team are telephone, weekly meetings, and emails. Plans are exchanged electronically in PDF or DWG format, either by email or via a FTP server. The design professionals are still using 2D Autocad to produce construction documents. Plans are submitted on construction site in hard copy. None of the team members have used BIM technologies in the past, and the impact of using BIM on their practices is not yet clear at all.

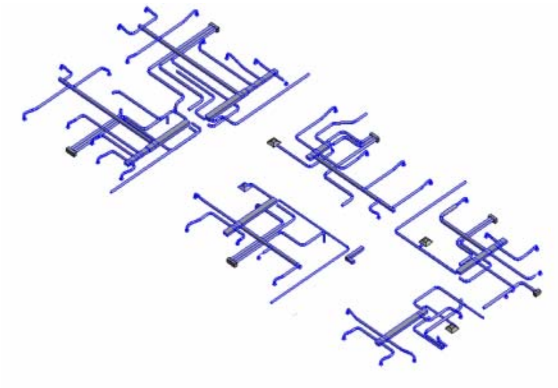
Our strategy was to develop a BIM model from the Autocad files to present the advantages of 3D visualization and clash detection to the team. We also installed an interactive table projector in the construction trailer to show how electronic 2D and 3D drawings could be annotated, shared and stored (Figure 2). The assumption was that the design professionals had their drawings completed at 100% prior to the start of construction, which was not the case. A lot of information was missing in the drawings, which made the production of an accurate model quite difficult, and was also the source of a lot of rework and idling time on the site, seeking and waiting for clarifications on incomplete or badly coordinated details.



Structural model



Architectural Model



Mechanical model : second floor

Figure 2: BIM Models

Worst, mechanical and electrical drawings were delivered floor by floor a few days before the work began on these floors. Site coordination using 3D visualization and clash detection was impossible without data related to these disciplines. Therefore, the demonstration of the use of the model and the interactive table projector (Figure 3) was much less convincing. Moreover, the team members had little interest in exploring more efficient ways in managing the construction process.

Figure 3: interactive table projector

Three attitudes concerning BIM implementation have been observed during interviews. They depend on the role of actors: 1) Levels of motivation are variables for client and project manager; 2) Hesitation / Resistance to change for the structural engineer: using a new technology needs time to get a good level of experience. 3) Resistance to change for the contractor: no added value in using BIM. On the other hand, three factors preventing the introduction of new technologies have been identified: 1) Human factor: a gap of level of knowledge on Information Technology and Communications between the client and the various project stakeholders; 2) Time factor: lack of time for implementation; 3) Financial factor: the initial investment is too costly (software, computers, training) especially for SMEs in the construction sector.

A new strategy was devised, introducing new cloud technology tailored to the specific needs of site coordination and quality control that are accessed through IPAD or Windows 8 tablets. One has been selected for the test site because it was best framed in terms of the technical requirements for commissioning the condos' units. This tool has been used by the Superintendent and the client in their daily tasks. The goal of the tool implementation on the site were: 1) to document its use for the management of site information, 2) to verify if the tool improved the process of sharing of information, 3) to observe in context how the tool was utilized and gather information vis-à-vis its use.

The users confirmed that the tool increased the overall performance of the commissioning process in matters of time and quality. However, since the project was almost completed, there was not enough time for them to fully master the full potential of the cloud platform.

5.2 Processes

As opposed to other industries, work is not organized around processes and workflows, but around activities and tasks. As demonstrated by research in Lean construction (Koskela, 2000) project management methods used in construction perform poorly in the control of the production process, first because the discrepancies between the planned schedule and the reality of the construction site, and also because there is no personal commitment from the workers to execute the activities or tasks as planned. Another problem is that the information and the work flows are not managed.

To better understand the information exchange within the project team, how they collaborate and share information, and to identify gaps in the workflow, a representation of information flow (Figure 3) has been established basing on collected data from interviews and focus groups.

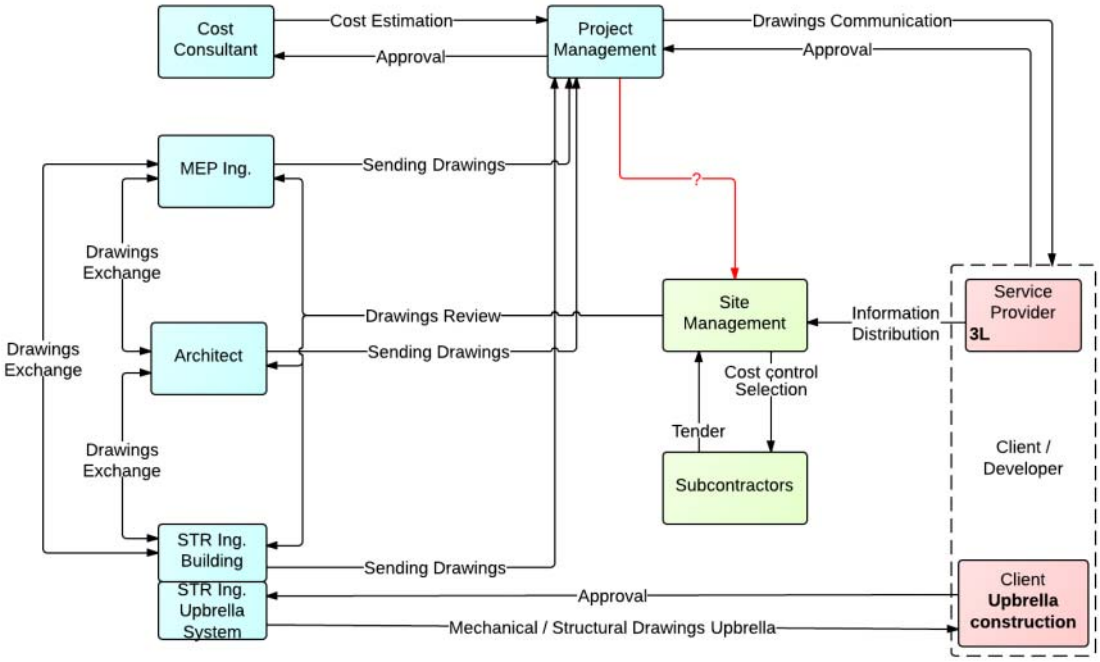


Figure 3: Information Flows Chart

The numerous iterations with the members of the team to establish the communication flows highlight the difficulty within the team to understand and map the information flow in a clear way. The consequence is information redundancy, which is related to the fact that the project has many "leaders": the lack of effectiveness and robustness of the communication flow were the source of errors, omissions, delays, and rework.

Decisions are taken and transmitted via two main channels: site meeting and email communications. Problems identified in regards to the site meeting are: 1) Meetings were regular, but not continuous; 2) Meeting minutes were not tracked after meetings; 3) Meetings attendances were irregular. Problems identified in regards to the e-mails communication are: 1) Tracking problems; 2) Information has not been sent to all the concerned actors; 3) Delays in replying to emails; 4) Problems in information interpretation; 5) Lack of responsibility after sending emails. Finally, two sources of delays in the construction site works have been identified: 1) Decisions issues: The client takes a long time to respond to comments from site, and 2) Plans issues: plans are not complete, and there is a delay in sending them to site.

This lack of consistency in the management of information and workflows was reflected by the inconsistencies in the organization of work which was responsible for a quite poor productivity. A member of the research team has carried out the site observation and productivity measurement throughout the construction period. The objective was to document the construction work, and to identify current practices and problems during site work, such as the sources of waste in construction field. Nine indicators were selected to measure productivity. However, because of the high variability in the way work was conducted, it was impossible to track these indicators efficiently. A value stream approach was therefore adopted to measure productivity. According to Forbes (2011), a value stream is all the value added actions and non-value added actions currently, which are required to create a product from raw materials and decision management. Value stream mapping (VSM) focuses on information management and transformation tasks. The VSM process generates a current-state map, a future-state map, and an implementation plan. The main production processes are represented by distinguishing between value-adding and non-value-adding activities. Rother (2009) explains that the VSM helps to see the wastes and the sources of wastes. The analysis of the construction process of the second level has highlighted a too high lead-time. The Value Creating Time (VCT) has been measured to 195 hours while the Lead Time (L/T) was equal to 462 hours (the average duration of work was defined to 7 hours a day). Accordingly, the productivity criteria (the ratio between the VCT and the L/T) are equal to 42%.

The site observations allowed us to identifying a list of wastes on field; this list has been also compared with the client's observations to highlight the most important problems in construction field. Table 1 presents site observations, sorted and classified into three main categories: Requirements definition, Human factors, and Information transfer.

Table 1: Wastes sources in construction site

Category	Wasteful
Requirements definition	• Lack of requirements definition for each module associated with a co-contractor; • Fuzzy definition of the tasks of each one; • Fuzzy Organizational links between stakeholders and concerning decision-making processes; • Rework; • Lot of wasted time in the management; • Fluctuation of production; • Over-production and under-production of some teams; • Standby Time: a lot of spaces are not used by workers; • Bad coordination of orders for materials; • False starts of some activities; • Lack of definition of the decision boundaries; • Poor equipment to perform the work; • Disparity in the efficiency of the used machinery; • Inconsistency between building systems; • Lack of systematic construction processes.

Category	Wasteful
Human factors	• Lack of motivation among workers; • Poor working method (lack of qualification of workers); • Working in silos; • Urgent decisions must wait the weekly meeting; • Long delays approval of shop drawings; • Deadlines for agreement with the subcontractors; • Centralized decision-making; • No final decisions; • Lack of decision monitoring;
Information transfer	• Delays of plans production; • Incomplete plans; • Problems of interpretation; • Non-compliance plans following a change request; • Redundancy in the information exchange.

5.3 Organization

To better understand the delivery process and the contractual relationship between the members of the project team, we have represented the organization of the project based on data that has been collected from the interviews (Figure 4). It should be noticed that the organization chart has never been defined by the project team, which has some adversarial impacts on the workflow.

Several issues related to organizational structure and context of the project have been identified. The perception of roles was ambiguous; two firms were involved in the project management and the limits of responsibilities were not well defined. That had impacts on the construction site works, where delays have been noticed because of incomplete plans, a lack of information due to the work in silo, as well as a coordination problem.

The functional analysis of business processes around the project allowed us to identify the problems in current practices, and figuring out the sources of waste. In order to validate and evaluate our findings, complete some missing information, and share experiences that could help in defining the solution to improve productivity; a focus group with the key project actors has been used. Six participants attended the focus group that was held in the construction site on the early November 2012: the architect, the contractor, the client, the site superintendent, and his two assistants. As mentioned earlier, the list of observed wastes helped in the preparation of the focus group session. Four topics have been identified to initiate the discussion between participants: 1) productivity; 2) exchange of information; 3) rework; and 4) perspectives regarding the new construction system. For each topic, the observed problems were noted in directly during the meeting, and then participants were asked to rank them anonymously by priority to identify the main barriers to be addressed in future projects. Table 2 shows factors that have been judged by the stakeholders during the focus group session, as important to be taken into consideration.

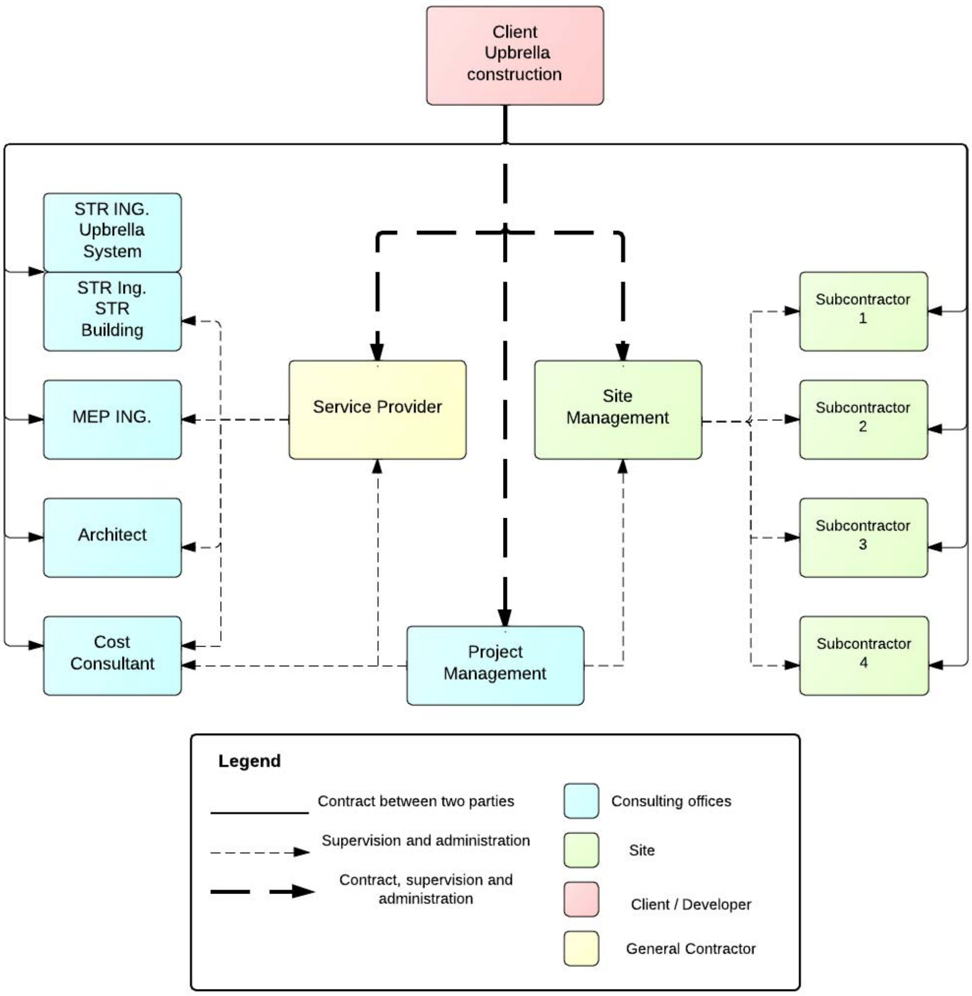


Figure 4: Organizational Chart of the project

Table 2: Important factors issued from focus group

Topics	Identified Factors
Factors that influence the productivity	1. Clarity of the information to the worker 2. Quality of worker's experience 3. Tools and equipment

Topics	Identified Factors
Problems in information exchange	1. Many "Leader" 2. Delay in decision 3. Coordination between field and offices 4. Availability of information at the workstation (on site)
Reason of Rework	1. Misinterpretation and misreading 2. Changes in client requirements during the construction work 3. Initiatives that do not comply with the plans
Construction System advantages	1. Weather protection 2. Funding 3. Systematization of the realization of floors
Barriers of using the Construction System	1. Changing habits 2. System integration 3. Early involvement in the project

A questionnaire has been completed at the end of the session, to determine the primary problem to be solved in priority, and to have a feedback on the activity. Results issued from the discussion, as well as from the questionnaire, showed a correlation with our analysis in step 1 and 2. In other word, the poor communication is the main problem in this project.

6. DISCUSSION AND CONCLUSION

The objective of the research was to use the lessons learned from observations and interventions on the construction process to devise a concept of operation for the successful deployment of the Upbrella system using BIM technologies and Lean methods for the control of production. We realized from our observations and findings that fundamental issues with the traditional organization of work for residential projects would had made the experiment of Lean and BIM impossible in such context, the core problem being the inadequacy of the current business model used to deliver small and medium residential projects. It was therefore essential for the enterprise to review its strategy and business model in order to have an adequate control on the project design and delivery process to reduce variability and related waste.

The proposed model involves the development of in-house resources: in BIM for the development and the management of the production of the building model, in the control of production by acting as construction manager and establishing long-term partnerships with sub-trades that are committed to the adoption of Lean and BIM practices. The aim is to have the level of control on the design and construction process necessary to establish the appropriate workflows, dataflows, and continuous improvement methods.

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THE IMPORTANCE OF ADDITIONAL CRITERIA IN SOLVING TRANSPORTATION PROBLEM

Mario Galic
Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering Osijek, Osijek, Croatia, mgalic@gfos.hr

Zlata Dolacek Alduk
Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering Osijek, Osijek, Croatia, zlatad@gfos.hr

Ivica Zavrski
University of Zagreb, Faculty of Civil Engineering Zagreb, Zagreb, Croatia, zavrski@grad.hr

Abstract

Simulation of the discrete and continuous business and production processes nowadays is a vital segment which enhances planning and defining phases of the construction projects. Authors have highlighted the possible improvement in computer programs (Solvers) for organizational processes modelling which was demonstrated on the computer simulation example of the asphalt production and transportation. Program of asphalt production and transportation was modelled as a linear program known as transportation problem. Initial model, structured by the potential asphalt plants (sources) which were required to fulfil the need and to supply the certain road-construction sites (destinations) while maintaining as a balanced model with the structural conditions and with the minimal transportation costs as an objective function, was expanded by three additional criteria: mean cost of the asphalt transportation from each source to each destination, median cost of the asphalt transportation from each source to each destination and the nominal source capacity. For further simulation of the transportation problems authors made a computer program MCS (Multiple Criteria Solver) which contained the mentioned criteria in order to achieve an optimal solution of the asphalt transportation with the continuous record of information: model which has offered the optimal solution, criteria that offered optimal solution, savings in respect of the initial model and production increase in respect of the initial model. It was noted that optimal transportation programs in a small number of cases were gained by the initial model. This means that even that initial transportation program satisfies all the structural conditions, without mentioned additional criteria check it could offer a sub-optimal solution. Model evaluation through these three criteria is necessary and it will ensure the optimal solution of the transportation problem.

Keywords: modelling, optimization, simulation, transportation problem.

1. INTRODUCTION

Linear programming (LP) is an operation research set of methods which are frequently used in construction practice in order of industry optimization. In term of LP, programming refers to mathematical programming, to a planning process that allocates resources: labour, materials, machines, or capital, in the optimal way so that costs are minimized or profits are maximized (Reeb and Leavengood, 2002). For solving some specific problems of LP, such as transportation problem (TP), in other words problem of optimal resource allocation, simplex method is the most used method. All LP problems that satisfy assumptions: proportionality, non-negativity and linearity of objective function, can be solved by simplex method (Stojiljković and Vukadinović, 1984). Nowadays, this method in construction practice is a bit neglected, and the main reasons for that are its relatively long calculation time and eventual complexity. Computer usage can make this method faster and what is more important repetitive, even more usable.

In past 50 years numerous research papers were published on this subject and many computer programs were made which are used in solving TP. Authors made a comparison of 5 computer programs (Solvers) and stated which of them is more or less applicable for engineering practice, and their potential modification. One characteristic common to all analyzed Solvers is that when the program fulfils the given restrictions it offers a solution with use of all the potential sources and with their maximal capacity, based on the assumption that all the given sources have to be involved in program to provide an optimal solution. If the objective function is the minimal transportation cost this assumption doesn't necessary has to be true. In this paper authors have proven this thesis.

2. METHODOLOGY

First step of the research was the literature review. Second step was comparison and evaluation of the computer programs – Solvers by solving a TP 10/10 model (10 sources supply 10 sites with generated values of the source capacities, site demands and unit costs of transportation) with Solvers: MS Excel Solver 2010, MS Solver Foundation, Palisade Evolver 6, TORA software and LINDO software. After the Solver comparison it was concluded that MS Excel Solver 2010 is the most suitable for further research. Third part of the research was structuring the Multiple Criteria Solver (MCS program) in MS Excel for generating and simulating transportation problems. In MCS by changing the input parameters 4 sets with 100 cases of TP 10/10 model were simulated.

3. LITERATURE REVIEW

The simplest definition of the transportation problem would be that it is a problem which is solvable by linear programming of transportation schedule of goods from multiple origins to multiple destinations with certain objective function such as minimal transportation expenses, minimal total time, minimal travel time, maximum quantity of transported goods (Dobrenić, 1978, Churchman et al., 1971, Kumar and Kaur, 2012). In this paper focus was on the minimal transportation expenses as an objective function. Therefore, objective of the transportation model is to determine the delivery schedule which will minimize delivery costs while satisfying demand of goods. So the best matching definition of transportation problem suggested authors in (Hillier et al., 1990, pp. 354) saying "*In particular, the general transportation problem is concerned (literally or figuratively) with distributing any commodity from any group of supply centres, called **sources**, to any group of receiving centres, called **destinations**, in such a way as **to minimize the total distribution cost***".

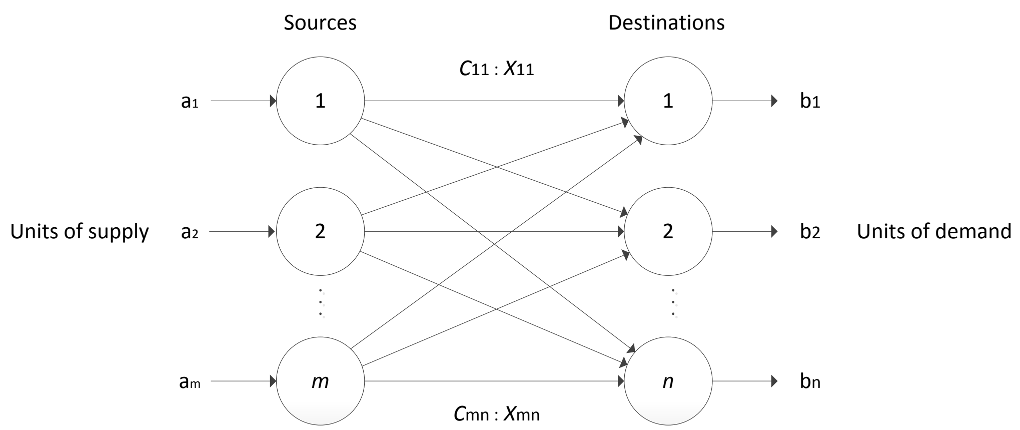


Figure 1 – representation of the transportation model with nodes and arcs (Taha and Taha, 1997)

Mathematical definition, explained graphically (figure 1), of the transportation problem is that it is a problem in domain of the linear programming with **m+n** equations and **m*n** variables (Dobrenić, 1978) in which **m** stands for number of sources and **n** number of destinations. Link (**i,j**) is a connection between certain source **i** and certain destination **j**, and which shows two very important facts: the cost of transport per unit of observed good **cij** and quantity of transported good **xij**. Quantity of produced good in source **i** was marked as **ai**, and demanded quantity of the same good in destination **j** is marked as **bj**. Models objective is to determine unknown quantity of transported goods **xij** which will produce minimal total expense satisfying all the conditions of production and demands (Taha and Taha, 1997).

The final mathematical expression of transportation model with minimization of transport cost as an objective function is:

$$\left[\min z = \sum_{j=1}^{m} \sum_{i=1}^{n} c_{ij} \times x_{ij}\right] \qquad \text{Eq. (1)}$$

With constraints:

$$\left[\sum_{j=1}^{m} x_{ij} = a_i, \qquad \sum_{i=1}^{n} x_{ij} = b_j\right] \left[x_{ij} \geq 0\right] \qquad \text{Eq. (2)}$$

Standard TP model can also be described (table 1) in matrix form as:

Destinations / Sources	B_1	B_2	B_3	B_n	a_i
A_1	X_{11} C_{11}	X_{12} C_{12}	X_{13} C_{13}	X_{1n} C_{1n}	a_1
A_2	X_{21} C_{21}	X_{22} C_{22}	X_{23} C_{23}	X_{2n} C_{2n}	a_2
A_3	X_{31} C_{31}	X_{32} C_{32}	X_{33} C_{33}	X_{3n} C_{3n}	a_3
A_m	X_{m1} C_{m1}	X_{m2} C_{m2}	X_{m3} C_{m3}	X_{mn} C_{mn}	a_m
b_j	b_1	b_2	b_3	b_n	Σai=Σbj

Table 1 – matrix form of the transportation problem

Table 1 indicates one of the main characteristic of transportation model: it has to be balanced (Σai = Σbj), in other words “*transportation algorithm is based on the assumption that the model is balanced, meaning that the total demand equals total supply”* (Taha and Taha, 1997, pp. 196).

4. COMPUTER PROGRAMS – SOLVERS REVIEW

Nowadays a large number of available computer programs are applicable for solving linear and non-linear optimization problems. They are either stand alone programs or they are add-ins (part of software libraries). Authors have pointed 5 computer programs which are widely known and most accessible: MS Excel 2010 Solver, MS Solver Foundation, Palisade Evolver 6, TORA software and Lindo software. Authors have analyzed and rated these programs by their performances after solving examples of transportation problem 10/10 models. Assessment criteria were based on the author’s professional experience and area of paper’s research. Evaluated characteristics were: form of the program, ease of usage, requirement of prior knowledge of programming languages, possibility of modification by user and availability (table 2).

	Form of the program	User friendly	Requires prior knowledge of programming language	Possibility of modification	Availability
MS Excel 2010 Solver	ad-inn	yes	no	yes	free with MS Office
Palisade Evolver 6	ad-inn	yes	no	no	liscenced
TORA software	stand alone	yes	no	no	liscenced
MS Solver Foundation	ad-inn	yes	yes	no	liscenced
Lindo software	stand alone	no	yes	no	liscenced

Table 2 – computer programs rating

It has to be pointed out that this review and ratings of computer programs is subjective and made in the context of this research. All of the analyzed computer programs were successfully applied in solving transportation problem. One characteristic common to all analyzed Solvers is that in order to fulfil the given restrictions program uses of all the potential sources and with their maximal capacity, based on the assumption that all the given sources have to be involved in program to provide an optimal solution. As it shown in table 2, authors have stated that MS Excel 2010 Solver is most suitable tool for further research.

5. PROBLEM FORMULATION

Initial model (table 1), which was structured by the all potential asphalt plants (sources) which were required to fulfil the need and to supply the given road-construction sites (destinations) while maintaining as a balanced model with the structural conditions and with the minimal transportation costs as an objective function, was expanded by three additional criteria (table 3):

– Mean cost of the asphalt transportation from each source to destination mean cij,

– Median cost of the asphalt transportation from each source to each destination median cij,

– Nominal source capacity.

		Destinations						
Sources	Nominal capacity [tons/hour]	B1	B2	B3	Bn	capacity - ai [tons]	mean cij [€/ton]	median cij [€/ton]
A1	NC1	X11	X12	X13	X1n	a1= (NC1/ΣNCi) *Σbj	mean c1j	median c1j
		C11	C12	C13	C1n			
A2	NC2	X21	X22	X23	X2n	a2= (NC2/ΣNCi) *Σbj	mean c2j	median c2j
		C21	C22	C23	C2n			
A3	NC3	X31	X32	X33	X3n	a3= (NC3/ΣNCi) *Σbj	mean c3j	median c3j
		C31	C32	C33	C3n			
Am	NCm	Xm1	Xm2	Xm3	Xmn	am= (NCm/ΣNCi) *Σbj	mean cmj	median cmj
		Cm1	Cm2	Cm3	Cmn			
	ΣNCi	b1	b2	b3	bn	Σbj=Σai		
		demand - bj [tons]						

xij [tons]; cij [€/ton]

Table 3 –expanded initial TP model

5.1. Multiple Criteria Solver (MCS)

Authors propose possible modifications which were demonstrated in computer program MCS (Multiple Criteria Solver) structured by authors for solving transportation problem of asphalt production and transportation. Program's platform is made in MS Excel 2010 and for solving TP it uses Excel's add-in Solver. Program is structured from 3 parts (table 4):

1. input parameters – structuring the initial model (sources input: number and nominal capacities, demands input and unit transportation costs)

2. solving the TP by 3 criteria - from the initial model till 2/n model

3. results analysis – optimal solution (optimal model)

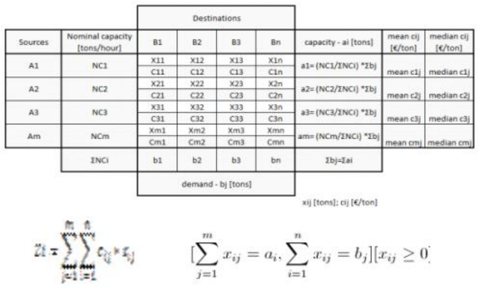
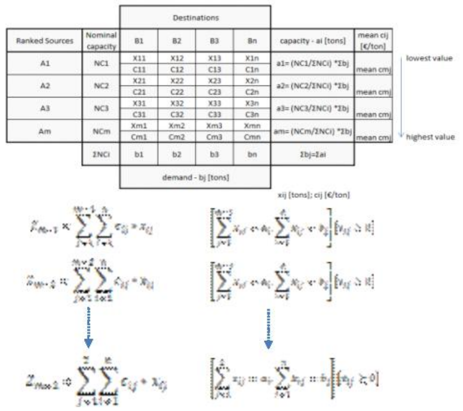
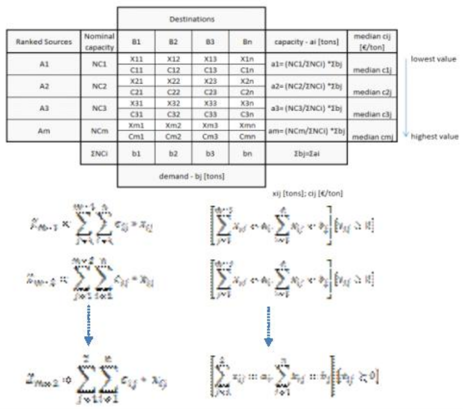
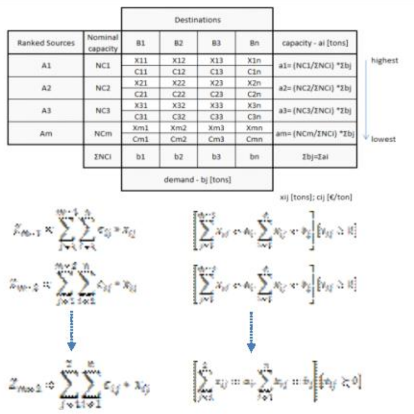
<table>
<tr><td rowspan="4">Input - Initial Model m/n</td><td>Structure the initial TP model with the m potential sources and given n destinations with constraints and the minimal transportation cost as a objective</td><td rowspan="4"></td></tr>
<tr><td>Expand the initial model with 3 criteria: mean cij, median cij and nominal capacity</td></tr>
<tr><td>To keep the model balanced distribute the total demand to the sources in regard to their contribution in total nominal capacity</td></tr>
<tr><td>Solve the initial m/n model and record the result → Zi</td></tr>
<tr><td rowspan="6">Sort and solve initial model according to criterion of mean cij values</td><td>Sort m/n model by mean cij criteria: from the lowest to highest value</td><td rowspan="6"></td></tr>
<tr><td>Remove the source with the highest mean cij value → m-1/n model</td></tr>
<tr><td>Solve the m-1/n model and record the result → Z_{m-1}^{mean}</td></tr>
<tr><td>Remove the source with the second highest mean cij value → m-2/n model</td></tr>
<tr><td>Solve the m-2/n model and record the result → Z_{m-2}^{mean}</td></tr>
<tr><td>Remove one by one source with the highest median cij value till 2/n model, solve them and record the results</td></tr>
<tr><td rowspan="6">Sort and solve initial model according to criterion of median cij values</td><td>Sort m/n model by mean cij criteria: from the lowest to highest value</td><td rowspan="6"></td></tr>
<tr><td>Remove the source with the highest mean cij value → m-1/n model</td></tr>
<tr><td>Solve the m-1/n model and record the result → Z_{m-1}^{median}</td></tr>
<tr><td>Remove the source with the second highest mean cij value → m-2/n model</td></tr>
<tr><td>Solve the m-2/n model and record the result → Z_{m-2}^{median}</td></tr>
<tr><td>Remove one by one source with the highest median cij value till 2/n model, solve them and record the results</td></tr>
<tr><td rowspan="6">Sort and solve initial model according to criterion of sources nominal capacity</td><td>Sort m/n model by nominal capacity criteria: from the highest to lowest</td><td rowspan="6"></td></tr>
<tr><td>Remove the source with the lowest nominal capacity → m-1/n model</td></tr>
<tr><td>Solve the m-1/n model and record the result → $Z_{m-1}^{nom\ cap}$</td></tr>
<tr><td>Remove the source with the second lowest nominal capacity → m-2/n model</td></tr>
<tr><td>Solve the m-2/n model and record the result → $Z_{m-2}^{nom\ cap}$</td></tr>
<tr><td>Remove one by one source with the lowest nominal capacity till 2/n model, solve them and record the results</td></tr>
<tr><td rowspan="3">Results analysis – optimal solution</td><td>Find the lowest result (transportation cost) among the (m-1) * 3 criteria results</td><td rowspan="3">
<table>
<tr><td></td><td></td><td colspan="3">criteria</td></tr>
<tr><td></td><td></td><td>mean cij</td><td>median cij</td><td>nom cap</td></tr>
<tr><td rowspan="5">models</td><td>m/n</td><td>Zi</td><td>Zi</td><td>Zi</td></tr>
<tr><td>m-1/n</td><td>$Zm\text{-}1^{mean}$</td><td>$Zm\text{-}1^{median}$</td><td>$Zm\text{-}1^{nom\ cap}$</td></tr>
<tr><td>m-2/n</td><td>$Zm\text{-}2^{mean}$</td><td>$Zm\text{-}2^{median}$</td><td>$Zm\text{-}2^{nom\ cap}$</td></tr>
<tr><td>⋮</td><td>⋮</td><td>⋮</td><td>⋮</td></tr>
<tr><td>2/n</td><td>$Zm{=}2^{mean}$</td><td>$Zm{=}2^{median}$</td><td>$Zm{=}2^{nom\ cap}$</td></tr>
</table>
minZ</td></tr>
<tr><td>Record the model and criteria that offered the optimal solution → minZ</td></tr>
<tr><td>Compare the optimal solution with the solution Zi of the initial m/n model</td></tr>
</table>

Table 4 – process of solving TP with MCS

5.2. Simulation - solving TP in MSC

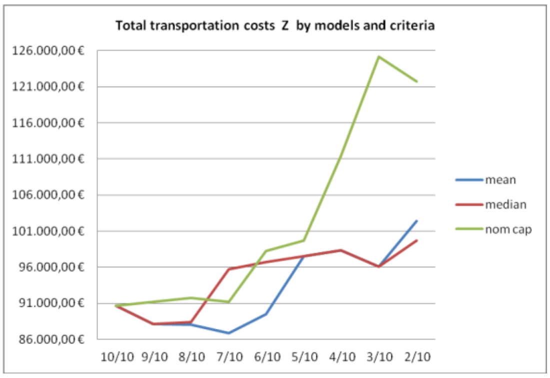
By changing the input parameters 4 sets with 100 cases of TP 10/10 model were simulated. Varied parameters were: transportation costs cij, demands by destination bij and sources nominal capacities NCij. Each set of simulated cases represents the potential situations of TP (table 5).

First set of simulated cases represents situations when sources capacities significantly varies (nominal capacity maximal/minimal ratio is 1.67) and sources are dispersed in relation to the destinations (maximal/minimal transportation costs cij ratio is 3.0) which demands also varies significantly (maximal/minimal ratio is 2.205).
Second set is derived from the first set and represents situations when sources capacities doesn't vary as much as in the 1st set (nominal capacity maximal/minimal ratio is 1.20). Nominal capacities of the potential sources are more uniform while they are still dispersed in relation to the destinations (maximal/minimal transportation costs cij ratio is 3.0) which demands also varies significantly (maximal/minimal ratio is 2.205).
Third set is derived from the first set and represents situations when sources capacities varies same as much as it did in the 1st set (nominal capacity maximal/minimal ratio is 1.67) but sources are not so dispersed in relation to the destinations (maximal/minimal transportation costs cij ratio is now 1.20). Destinations demands still significantly varies (maximal/minimal ratio is 2.205).
Fourth set was derived from the 1st set and it represents the situations when sources capacities varies same as much as it did in the 1st set (nominal capacity maximal/minimal ratio is 1.67), sources are not so dispersed in relation to the destinations (maximal/minimal transportation costs cij ratio is now 1.20), but destinations demands are more even (maximal/minimal ratio is 1.20)

Recorded analyzed results were related savings of optimal models and their solutions over the initial model and its solution in each set of TP cases (table 5):

$$\frac{(Z_i - minZ)}{Z_i} \qquad \text{Eq. (3.)}$$

And an increase in production as a result of reductions of sources in relation to the initial model (figure 2):



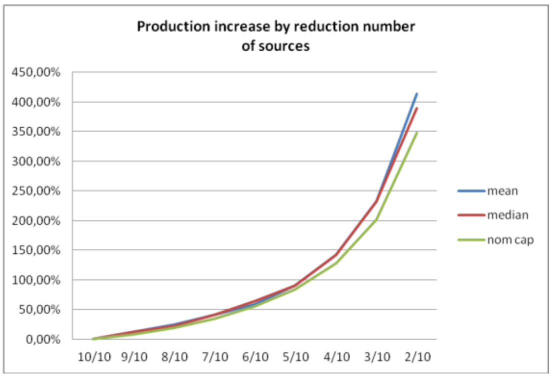


Figure 2 – graphical example of recorded simulation results of minimal transportation cost gained by certain model and criteria, and increase in production

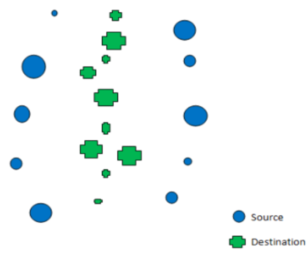
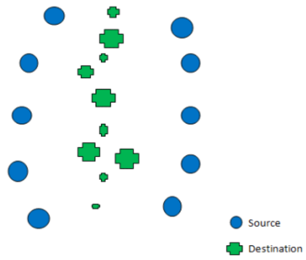
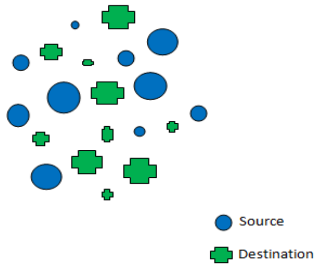
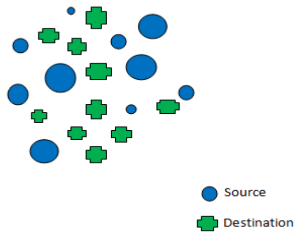
	Graphical representation of the initial simulated TP cases	Input parameters	Results
1st set		Number of simulated cases N=100 Initial model m=10 n=10 transportation costs cij generated from interval [7€/ton;21€/ton] → maxcij/mincij=3,0 demand by each destination bij generated from interval [680tons;1500tons] →maxbij/minbij=2,205 source nominal capacity NCij generated from interval [90tons;150tons] →maxNCij/minNCij=1,67	Summary Statistics **(Zi-minZ)/Zi** Mean= 0,031529 →**3,15%** Median= 0,027973 →**2.89%** Std.Dev.= 0,023961 Range= 0,106656 → **0% - 10.67%** Quartile Range= 0,0316 → **1.58% - 4.74%**
2nd set		Number of simulated cases N=100 Initial model m=10 n=10 transportation costs cij generated from interval [7€/ton;21€/ton] → maxcij/mincij=3,0 demand by each destination bij generated from interval [680tons;1500tons] →maxbij/minbij=2,205 source nominal capacity NCij generated from interval [100tons;120tons] →maxNCij/minNCij=1,2	Summary Statistics **(Zi-minZ)/Zi** Mean= 0,041945 → **4.19%** Median= 0,036469 → **3.64%** Std.Dev.= 0,035791 Range= 0,174568 → **0% - 17.47%** Quartile Range= 0,051108 → **1.2% - 6.32%**
3rd set		Number of simulated cases N=100 Initial model m=10 n=10 transportation costs cij generated from interval [14€/ton;16,8€/ton] → maxcij/mincij=1,20 demand by each destination bij generated from interval [680tons;1500tons] →maxbij/minbij=2,205 source nominal capacity NCij generated from interval [90tons;150tons] →maxNCij/minNCij=1,67	Summary Statistics **(Zi-minZ)/Zi** Mean= 0,005664 → **0.56%** Median= 0,004404 → **0.44%** Std.Dev.= 0,005148 Range= 0,028888 → **0% - 2.89%** Quartile Range= 0,005645 → **0.20% - 0.76%**
4th set		Number of simulated cases N=100 Initial model m=10 n=10 transportation costs cij generated from interval [14€/ton;16,8€/ton] → maxcij/mincij=1,20 demand by each destination bij generated from interval [1000tons;1200tons] →maxbij/minbij=1,2 source nominal capacity NCij generated from interval [90tons;150tons] →maxNCij/minNCij=1,67	Summary Statistics **(Zi-minZ)/Zi** Mean= 0,004637 → **0.46%** Median= 0,004015 → **0.40%** Std.Dev.= 0,003741 Range= 0,013789 → **0% - 0.14%** Quartile Range= 0,005977 → **0.13% - 0.72%**

Table 5 – TP simulated cases and results

6. DISCUSSION

It is shown that savings of total transportation costs in relation to the initial model total transportation cost were reported in all four sets of simulated TP cases. The highest savings were spotted in first and second set of TP cases where sources were dispersed in relation to the destinations (mean savings are 3.15% in 1st set and 4.19% in the 2nd set). Savings were spotted in the 3rd and 4th set of cases of TP but smaller (mean savings are 0.56% in 3rd set and 0.46% in the 4th set). Only in 10% of the simulated cases the initial model was the model which offered the optimal solution. In none of the simulated cases model 2/n was the model which offered optimal solution. Also it is recorded that verification by all three criteria is necessary because all of the given criteria have given in some cases the model which provided an optimal solution.

7. CONCLUSIONS

According to the given results it can be concluded that the multi-criteria test in solving TP is necessarily needed in order to be sure that an optimal solution of the problem was achieved, if the only objective function is minimum transportation costs. It is proved that only in 10% of cases initial model, which implies involvement of all the potential sources, will be the model which provides the optimal solution. However, due to reduction of the number of sources, taking into account the assumption of balanced model, production will increase. The increase in production will be manifested by either lengthening the time of production or increasing the nominal capacity, while maintaining constant production time.

Analyzed computer programs - Solvers so far have not provided the opportunity of these criteria verification. Potential implementation of this criteria check option in mentioned computer programs doesn’t require any conceptual changes. MCS program has proven to be a useful tool but rough software for commercial use. It will serve as a basis for further research and development of a computer program that will work towards this conception.

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OPTIMIZATION OF COMPONENT SIZE IN MODULAR CONSTRUCTION

Chirag Garg
Wight and Company, Chicago, U.S.A, cgarg@wigtco.com

Bryan Hubbard
Purdue University, West Lafayette, In, U.S.A, bhubbard@purdue.edu

Abstract

This paper provides information on newly developed software routines to optimize the module size for mechanical systems in commercial building projects. The primary objective of optimization is to increase productivity and maximize the size of a module. Prefabrication and modularization has been used in the construction industry for decades. It has recently made a resurgence worldwide providing increased productivity, safety and quality. Renovation of a large educational building was used to develop and validate the optimization software. The facility's entire HVAC system was completely replaced in the existing structure creating unique constraints for the prefabricated module size of the HVAC components.

To construct the mechanical system, it is divided up into modules of optimum size that maximize the productivity. The optimization routine utilized Microsoft Excel based optimization tools. Generalized reduced gradient (GRG) nonlinear method as a basis, with application of 'Pareto optimal' method is used to perform the relevant optimization. Equations for constraints and the objective were derived using the relationships established amongst the parameters length, width, height, and weight. In the optimization model, length, width and height of the module were determined as the variables while volume of the module was maximized and connection time was minimized as objectives.

The resulting optimization routines provided the optimized HVAC module size for the facility. The result of this research is an optimized module for the relevant project and an optimization tool to assist contractors in sizing mechanical system modules. Future research is underway to utilize the optimization tool in conjunction with three-dimensional BIM models to divide the facility into optimal sized modules based on specific project constraints.

Keywords: HVAC, mechanical system, module optimization, prefabrication.

1. INTRODUCTION

This study focuses on the development of an optimization routine for prefabrication of a commercial HVAC system. The optimization routine could be standardized as required for application on various projects. The focus of the study was on the prefabrication of the mechanical system for an educational facility. Prefabrication techniques will be employed to the mechanical room located in the basement of the building with constrained access. The basement of the building is not undergoing any architectural or structural change, thus prefabrication is employed for renovation of the space. Prefabrication concepts along with mathematical optimization techniques will be used to address constructability issues. Optimization will be used to deconstruct the mechanical system for ease of prefabrication. As a result of this study an optimization routine will be developed for future use.

1.1 Background

The benefits of prefabrication in the construction industry are seen in terms of schedule, quality, and safety. The major benefit of prefabrication is its impact on the project schedule. With the use of prefabrication, a number of activities can be performed simultaneously (Blisman, Pasquire, & Gibb, 2007). This significantly reduces the total time required. In a survey conducted by Berstein, Gudgel and Laquaidara (2011), almost 35% of the participants using prefabrication reported a decrease in the project schedule by four or more weeks. Similarly, in a survey done for Hong Kong high rise buildings, it was noticed that the construction cycle per floor was reduced by four to six days per floor using prefabrication (Jaillon & Poon, 2008).

Quality was determined to be the second most important driving factor for prefabrication. Prefabrication assists the delivery of better and more consistent quality components as elements are constructed in a factory setting under controlled environmental conditions with minimal rework on site (Gibb & Isack, 2003).

Safety performance is also increased by using prefabrication. It has also been observed that prefabrication reduces the number of on-site personnel, ultimately increasing safety on the jobsite (Deemar, 1996, Gibb, 2001). Prefabrication also decreases the amount of scaffolding required, congestion on the jobsite, and health hazards because the environment of the prefabrication facility is much more controlled (Deemar, 1996). Prefabrication also supports sustainable construction in lean building techniques. Waste produced could be reduced by a minimum of 70% using prefabrication as compared to use of traditional construction methods. Concrete, reinforcement and plastering waste could be reduced by more than 90% (Tam, Tam, Zeng, & Ng, 2007). The Modular Building Institute (2010) reported “Modular construction methods and material allow a building to be more readily ‘deconstructed’ and moved to another location should the need arise, so complete building reuse or recycling is an integral part of the design technology” (p. 13).

Prefabrication techniques face a variety of challenges that include a lack of standardization, industry inexperience and time of design decision in the process of planning. Lennartsson, Bjornfot, and Stehn (2008) claimed that “Modularization requires standardization across the industry in order to improve production control” (p. 123). The general opinion in the industry is that prefabrication could be widely used in a market where all the joints of prefabricated systems are standard. Lennartsson, Bjornfot, and Stehn (2008) claimed the, “Core of modularization is the division of complex product into functional parts that are easier to manage individually than in relation to the whole” (p. 124). One major challenge is determining the size of the module to be produced. Limited quantitative data is available on the sizing of modules. This issue has not been substantially addressed although qualitative answers are provided, such as: the size should be such that the number of units are not very large or small, should be easy to transport and the time to produce each should not be long (Lennartsson, Bjornfot, & Stehn, 2008).

Inexperience and reluctance to experiment has hindered the growth of prefabrication. “Reluctance among clients, architects and contractors to adopt off-site production is that they have difficulty in ascertaining the benefit that such approach would add to project”, as quoted by Blisman, Pasquire and Gibb (2002, p. 126). Another challenge faced by prefabrication is that the design needs to be frozen at early stages with a high level of detail. Deemer (1996) said that, “More detailed project planning is necessary with modularization to ensure availability of design, components and material necessary to assemble modules” (p. 147). Further prefabrication reduces the flexibility in design and scope an owner has in the later stages of project cycle. (Construction Industry Institute (CII), 2002)

2. METHODOLOGY

The project used to develop the parameters in this research is an educational building. The building will be renovated to include classrooms, faculty offices, and research facilities. In addition to architectural changes, the umbrella of renovation also includes complete makeover of the mechanical and electrical systems. Prefabrication is used to address the constructability issues pertaining to a mechanical room located in the basement of the building. The pre-existing basement, including the mechanical room, will not be undergoing any major structural change, thus the issue associated with the mechanical room is to transfer the components into the room and assemble them with minimum disruptions. To improve the construction process and reduce the budget of the project, the contractor is looking to prefabricate all the equipment piping and sheet metal work associated with the mechanical room. The area of the room is approximately 2800 sq. feet and it will accommodate a range of boilers, heat pumps, glycol tank, an air handler, and an engine generator. It also has a variety of pipes and duct work serving the building that go in and out of the mechanical room.

In order to optimize the module size, optimization tools associated with a computer application will be utilized. Optimization of module size will aim to reduce the connections required on site while at the same time ensuring the transportation of the module is feasible.

The size of the module will also be restricted in order to move it around in the basement for storage and later installation.

The parameters associated with the optimization problem are as follows:

- Length of the module (L)
- Width of the module (W)
- Height of the module (H)
- Weight of the module (Z)
- Connection time required for 1X1 module (MT)
- Connection Time of the Module (T)
- Volume of the Module (V)

2.1 Model Development

Amongst the optimization software's available commercially Excel was chosen to be appropriate for the purpose. Excel is an easy to use platform that is very flexible in nature. Excel is universally accepted and interface could be linked to various other software platforms, for example, BIM. Optimization in Excel consists of two basic steps; one model development and two optimization of the model.

Model development in Excel consists of the following three basic steps:

1. Definition of the variables
2. Development of constraints and constraint equation
3. Development of an objective function that is derived out of the variables

Variables are described as a set of symbols that can assume any set of values in optimization. There are two types of variable, the input variables and the decision variables. Input variables are the values determined by the user that are usually fixed for a particular model. Input variables in the relevant optimization are; density of the module, dimensions of the complete mechanical system, time to connect a portion of the module. Decision variables are the variables subject to change with the progress of the optimization process. Decision variables in the relevant optimization model are; length of the module, width of the module, height of the module. Figure 1 show all the decision variable associated to a typical shape of the module. Constraints are limitations that restrict the scope and extent of the optimization solution to make it viable and practicable. The decision variables have maximum and minimum constraints. The constraints of the decision variables would be governed by the method of transportation and restrictions associated to in-house movement of the module from one place to another Table 1 shows all constraints with the maximum and minimum boundary of each. Simple inequality constrain equations are developed using the values in the table. These values are calculated on the basis of various project parameters determined using the plans and specifications of the project.

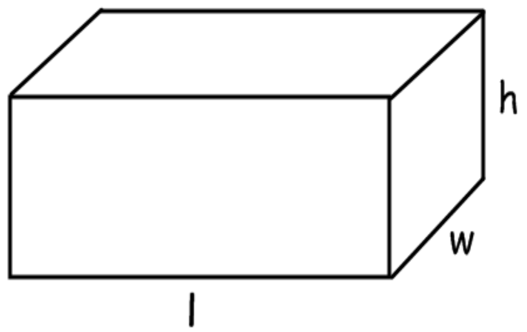

Figure1 Decision variables associated to a typical shape of the module

Table 1 Constraints with respective maximum and minimum limits

	Minimum	Maximum	Units
Length (L)	4	9.9	Feet
Width (W)	2	3.5	Feet
Height (H)	3	6	Feet
Weight(Z)	100	1000	Lbs

Objective functions define the purpose of optimization in terms of function and equations. The two objective functions that need to be maximized and minimized respectively for this research are:

Table 2. Objective functions and types.

	Type	Equation	Equation No.
Volume (V)	Maximization	$W = L \times W \times H$	
Connection Time (T)	Minimization	$T = W \times H \times MT$	

Assuming the module to be cube/cuboids in shape as shown in Figure 1, the volume of module will be the product of its length, width and height. Equation 1 shows the volume of the module as a function of its length, width and height of the module. Connection time of the module is the second objective and can be described as the product of width, height and time of connection for 1'x1' module (MT). This connection time is the total time required to freight, place and connect the module in place using the appropriate equipment.

The connection time for a 1'x1' module is known to be a function of weight. The smaller the module, the easier it is to handle. It also typically requires less equipment and/or lighter equipment, which results in quicker transition and assembly. As the size of the module increases, the module becomes more difficult to handle resulting in a higher transition time. The increased difficulty in connection leads to a requirement for additional equipment and labor hours. For the purpose of this research, the following equation was chosen it best suits the project and its constraining factors. Equation 3 represents time of connection for 1'x1' module as a function of weight.

$$MT = \frac{\left(\frac{Z}{100}\right)^3}{100}$$

For the purpose of optimization, Excel uses of Generalized Reduced Gradient (GRG) nonlinear optimization to find the best possible solution for a problem. As described earlier, relevant optimization contains two objectives, maximization of the volume and minimization of time required for connection. Excel Solver being limited in scope, Pareto Optimal method is used to perform multi-objective optimization within Excel.

2.2. Pareto Optimal Method

Named after Vilfredo Pareto, Pareto optimal is a measure of efficiency. A variety of definitions have been given to the term and the process with respect to its application, but the following description given by Winston, & Goldberg, 2003, best applies to this research.

"In a multi-attribute decision making situation in the absence of uncertainty, we often search for 'Pareto optimal' solutions. We will assume that our decision maker has two objectives, and that the set of feasible points under consideration must satisfy a given set of constraints. A solution (call it A) to a multiple objective problem is Pareto optimal if no other feasible solution is at least as good as A with respect to every objective and strictly better than A with respect to at least one objective.

If we define the concept of dominated solutions as follows, we can rephrase our definition of 'Pareto optimality. A feasible solution B dominates a feasible solution A to a multiple objective problem if B is at least as good as A with respect to every objective and strictly better than A with respect to at least one objective."

The Pareto optimal solutions are the set of all un-dominated feasible solutions. The values of the objective function can be graphed on either axis and a curve is obtained. This curve is called a Trade-off curve that establishes a relation between optimal values of two objectives.

Figure 2 shows a typical trade-off curve with two objective functions in a plane coordinate system. In the curve presented, objectives on x-axis and y-axis are minimized and maximized respectively. The shaded region represents all the feasible solution while the points on the curve correspond to all of the 'Pareto optimal solutions' that are in the un-dominated feasible solution.

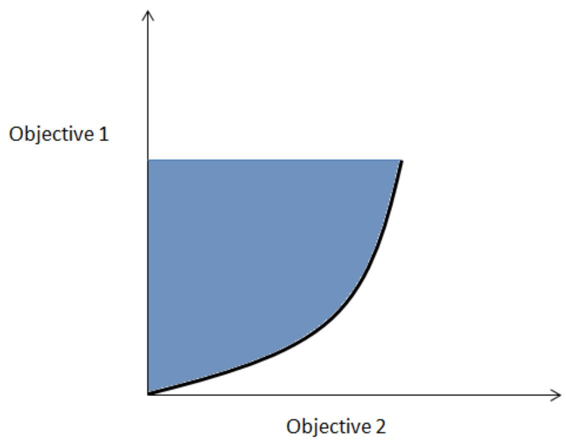

Figure 2 'Pareto optimal curve'

2.3 Optimal Solution

In order to apply Pareto Optimal method with Excel solver, the problem was divided into following two cases:

Case 1: Maximization of Volume (Single Objective)

Case 1 is the optimal solution when volume equation is maximized. The result is the maximum volume feasible with values of associated decision variables L, W and H. The connection time of the module was also calculated in order to perform the 'Pareto optimal' solution.

Case 2: Maximization of Volume ('Pareto optimal' Method)

Results from Case 1 are used and are considered to be a 'Pareto optimal' solution for Case 2. For the Case 1 solution not to be 'Pareto optimal', there would have to be a solution satisfying all the constraints that yields a higher value of volume and a lower value of connection time as compared to that obtained in Case 1. Since the solution obtained in Case 1 is a unique solution there is no other solution better than the solution from Case 1. However, a number of solutions can be determined that are as good as the solution obtained from Case 1 given a variation in connection time.

Case 2 presents the optimal solution of a maximized volume associated with a given set of connection time values. The total connection time is varied from the lower bound to the upper bound. A set of optimal volume solutions are generated for the given connection times resulting in multiple solutions that are graphed. The volume is graphed on the y-axis and connection times graphed on the x-axis. To derive these solutions a modified connection time equation is developed:

$$T(=W \times H \times MT) \leq Trial\,time$$

A variety of values of 'trial time' are used with the maximization of volume function. The volume function is constrained by all basic constraint equations represent in Table 1. as well as the connection time constraint. These values of 'trial time' are assumed to be smaller than the values of connection time obtained in Case 1. A value of length, width and height associated to the each 'trial time' is calculated. The tradeoff curve is generated using these values.

3. RESULTS ANDF CONCLUSIONS

3.1 Results

Case 1: Maximization of Volume (Single Objective)

The following values were determined using the Excel solver for Case 1. Table 3 provides the values of all decision variables and objectives values derived.

Table 3 Values of decision variables and objectives corresponding to Case 1

	Value	Units
Length (L)	9.9	Feet
Width (W)	3.37	Feet
Height (H)	6.00	Feet
Volume (V)	200	Cubic feet
Connection time of module (T)	202	Man hours

This is a simple test of optimization that is performed for two reasons; the first is to test the Excel model developed for its accuracy and precision. The second is a basis for the Case 2 optimization. As expected, the Case 1 optimization maximized the volume of the module by maximizing the length, width and height of the module. The size of the module was only constrained by weight of the module. Since the optimization was governed by the size and weight constraints, it can be concluded that if there were no constraints this process would always maximize in a way that the entire system could be prefabricated offsite and put in to place with no onsite connections required. However, in real life conditions this is not feasible and thus constraints were added for an acceptable, practical and realistic result.

Case 2: Maximization of Volume ('Pareto optimal' Method)

The following values were determined using the Excel solver with the Pareto optimal method for Case 2. Different values of 'trial time' were used to optimize volume objective. Table 4 tabulates different values of 'trial time' corresponding to the values of all the decision variables and objective functions derived.

Table 4 Different values of 'trial time' with corresponding values of all decision variable and objective function

Observed Values	**T-1**	**T-2**	**T-3**	**T-4**	**T-5**	**T-6**	**T-7**	**T-8**	**T-9**
Trial time (man hours)	0.1	0.5	1	5	10	50	100	150	200
Connection time for one module (man hours)	0.1	0.5	1.0	5.0	10	50	100	150	200
Volume (lbs/ft^3)	24	40	51.	79	94	141	167	185	199
Length (feet)	4	6.7	8.5	9.9	9.9	9.9	9.9	9.9	9.90
Width (feet)	2	2.0	2.0	2.3	2.5	2.8	3.0	3.3	3.49
Height (feet)	3	3.0	3.0	3.4	3.7	5.0	5.5	5.6	5.78
Weight (lbs)	120	202	255	396	471	705	838	928	997

Figure 3 is a plot of the variation of length, width and height versus connection time of the module. Figure 4 is a plot of the variation of the connection time of the module with the volume of the module. This curve is known as the optimal solution curve. Any point on the curve results in an optimal solution ratio of connection time of the module to the volume. Connection time is proportional to the volume and is directly proportional to the variation of length, width and height of the module

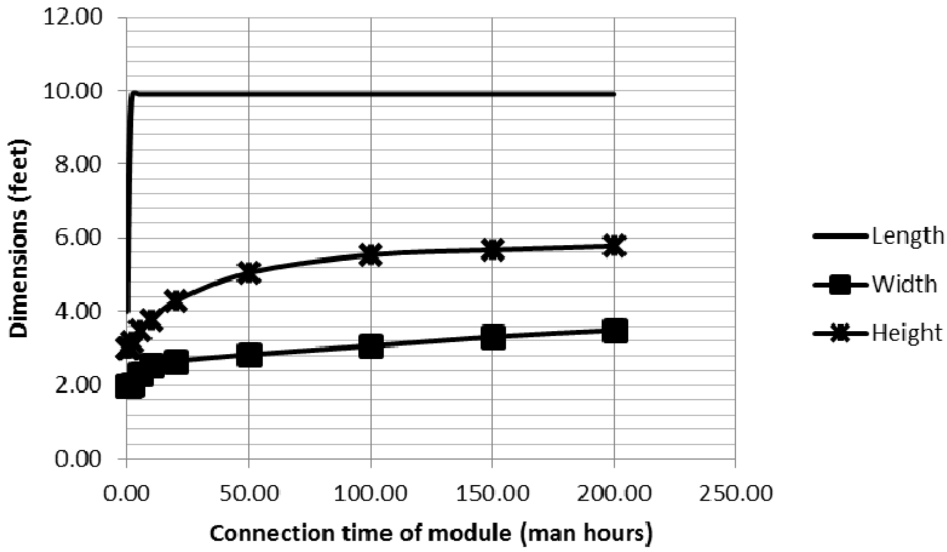

Figure 3 Graphs the variation of height, width and height of the module with the connection time of the module.

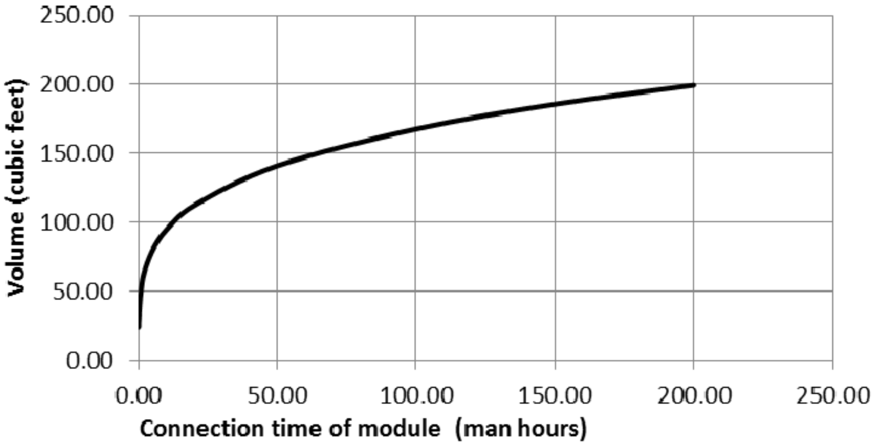

Figure 4 Graph representing curve of Volume to the connection time of the module

Case 2 utilizes the 'Pareto optimal' method and presents optimization results using both the volume and connection time of the module as objective functions simultaneously. Volume was considered to be the primary objective while the other objective function of connection time of the module was converted to a constraint as described in the 'Pareto optimal' method. Various trials were performed and values associated with each of these trials were tabulated. Tabulated values were used to obtain a graphical curve between the two objective functions, connection time and volume. Connection time pertaining to each module could also be directly associated to productivity for each module.

As presented in Table 4 and Figure 4 it was observed that volume increases substantially with a small increase in the connection time. As the module becomes larger a substantial increase in connection time results in a small change in module size. Thus it could be inferred that productivity is highest when the module is small and productivity decreases with an increase in module size.

3.2. Conclusion

Prefabrication is known as a technique to increase productivity in construction. The optimization routines developed through the research further increases the productivity of modularization by optimizing the size of the module. Renovation of a large educational building was used to develop and validate the optimization software. The facility's entire HVAC system was completely replaced in the existing structure creating unique constraints for the prefabricated module size of the HVAC component.

Microsoft Excel was used as a tool to develop the optimization model. Length, width, height and weight of the module were assumed to be decision variable in the process. The objective was set as the maximization of the volume of the module size and the minimization of the connection time required in the field. Multi objective optimization was performed using the

As Pareto optimal method based on the GRG nonlinear optimization model. Two cases were optimized and results were tabulated. Tabulated results were plotted to determine that optimum size of a prefabricated module is not necessarily the maximum or the minimum size possible.

One end of the curve represents a module with a small volume and small connection time leading to high productivity with a large number of total modules in the system. Other end of the curve represents a module with a large volume and long connection time leading to a low productivity with small number of modules in the system. Thus, optimal size of the module was determined to lie between the maximum and minimum volume of the module. Optimal size was not determined to be a fixed value in term of volume; rather it was determined to be a range of volumes that almost had similar productivity. For the project under consideration Figure 5 shows the desirable range of optimal size. This range was identified as the area where the curve is reaching the peak.

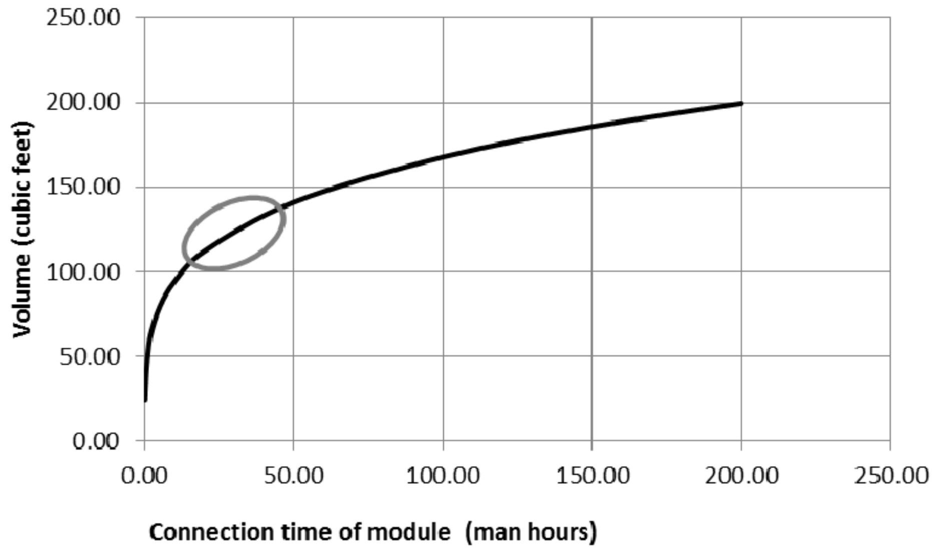

Figure 5 Optimal range of volume of the module

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FAILURE STRESS AS A MOTIVATOR FOR CREATIVE CONSTRUCTION MANAGEMENT

F. J. M. van Gassel
Eindhoven University of Technology, Eindhoven, the Netherlands, f.j.m.v.gassel@tue.nl

M. J. E. Visser
OCGH Advies, Advisory Service for Education, Helmond, the Netherlands, marjan.visser@ocghadvies.nl

J. E. M. H. van Bronswijk
Eindhoven University of Technology, Eindhoven, the Netherlands, j.e.m.h.v.bronswijk@tue.nl

Abstract

A building assignment is a complex task that demands collaborative working in order to achieve added value for users and society through creative construction management. Modular building systems are used in workshops in the building environment domain to make students aware of various phenomena that occur in the process of creative construction. Existing modular building systems used in training do not include the experience of failure as a motivator for creative construction. This article validates an innovative set of modular building materials (Handstorm®) that has a high innate risk of construction failure, as a tool in using failure as a motivator in creative construction. It reports on the effect of both innate failures – such as instability or collapsing – and emotional failures, such as the success of a competitor or losing a competition. The results indicate that the presence of failure stress is a valid motivator in teaching creative construction management.

Keywords: collaborative design, creative tools, education, failure stress, modular system

1. INTRODUCTION

Effective learning by experience is well developed and scientifically validated in the curricula of primary education. It stimulates discussion and the sharing of experience, and it encourages pupils to starts researching, which leads to the mastering of new skills and the development of concepts of thought (Laevers, 2000; Verhoeven, 2003). According to Gore (2003), studio teaching of architecture students whereby they obtained direct experience of construction materials, led to the same learning pattern, resulting in critical thinking and actual innovation, with failure of the construction as one of the best motivators. Failure as a motivator in effective design has a long history (Pretoski, 2006), but dependable educational tools to teach design teams this phenomenon are scarce, especially when large numbers of students are involved and studio teaching is the only available option.

Various modular building systems that allow for endless variations have been developed for studio teaching. LEGO® SERIOUS PLAY™ (LEGO) is a building system for teaching innovation of business strategy that is based on the work of Roos et al. (2006). It is a play in which building blocks and their connections are metaphors for communication, cohesion, and social bonding in constructing new organizations that are ready for the unexpected in order to maximize shareholder value. Success and co-ownership of the problem are the main motivators, not failure. This is also the case in the Lean Apartment Construction Game (LEAPCOM) (Sacks 2005), in which the aim is to construct an 8-story building with 4 apartments on each floor, each customized to the specific design specifications of individual home owners (ibid.). The conflicts that arise have to be solved and waste must be reduced. Collaboration among the partners in the building process is the subject taught, not the effect of failure stress.

In the context of this research, “failure is an unacceptable difference between expected and observed performance” (Carper, 1996). This difference can cause stress, and if the stress is not too low or not too high, the performances can be optimal (Seyle, 1978). The failure stress is then a motivator or a provocative stimulus. “Such stimuli are intended to provoke designers to consider various trains of thought that they might not otherwise think about” (Smith, 2006).

“Planned” failure intended to provide direct experience of team designing seems to ask for a different set of modular building materials. The aim of this report is to validate an innovative set of modular building materials as an educational tool in using failure as a useful motivator in teaching collaborative design.

2. THE TOOL AND ITS USE

The first author developed the Handstorm® Modular Building System (MBS), which has a high innate rate of building failure induction. The MBS consists of (see Figure 1A):

- 10 plywood disks, 600 mm in diameter, with 8 x 25 mm holes near the outer rim.
- 80 pine wood poles, 600 mm long, 22 mm in diameter, with 5 x 10 mm holes.
- 200 sticks, 600 mm long, 9 mm in diameter.
- 200 sticks, 100 mm long, 9 mm in diameter.

Upon inspection, it seems obvious that the poles have to go into the holes in the disk in order to build platforms of one or more stories high. The loose fitting of the poles in the holes, and the fact that the holes are placed in a large circle, causes the structure to fail as soon as it is loaded with some extra weight (Figure 1B). Stability and strength are improved by placing some of the thinner sticks in some of the pole holes (Figure 1C). Since these fittings are also rather loose, some thought has to be given to the direction and positioning of the sticks.

3. VALIDATION METHODOLOGY

Although the Handstorm® MBS is mainly meant for graduate and postgraduate teaching (Cases A & D), we decided also to use experimental groups of primary school children (Cases B & C) to find the limits of the educational application of the system. In all cases, a reward followed the completion of the task. The winning group of students earned a bottle of wine, while the losing group were given a bottle of lemonade. The winning group of school children were photographed on top of the completed platform. They could download their picture from the internet the next day.

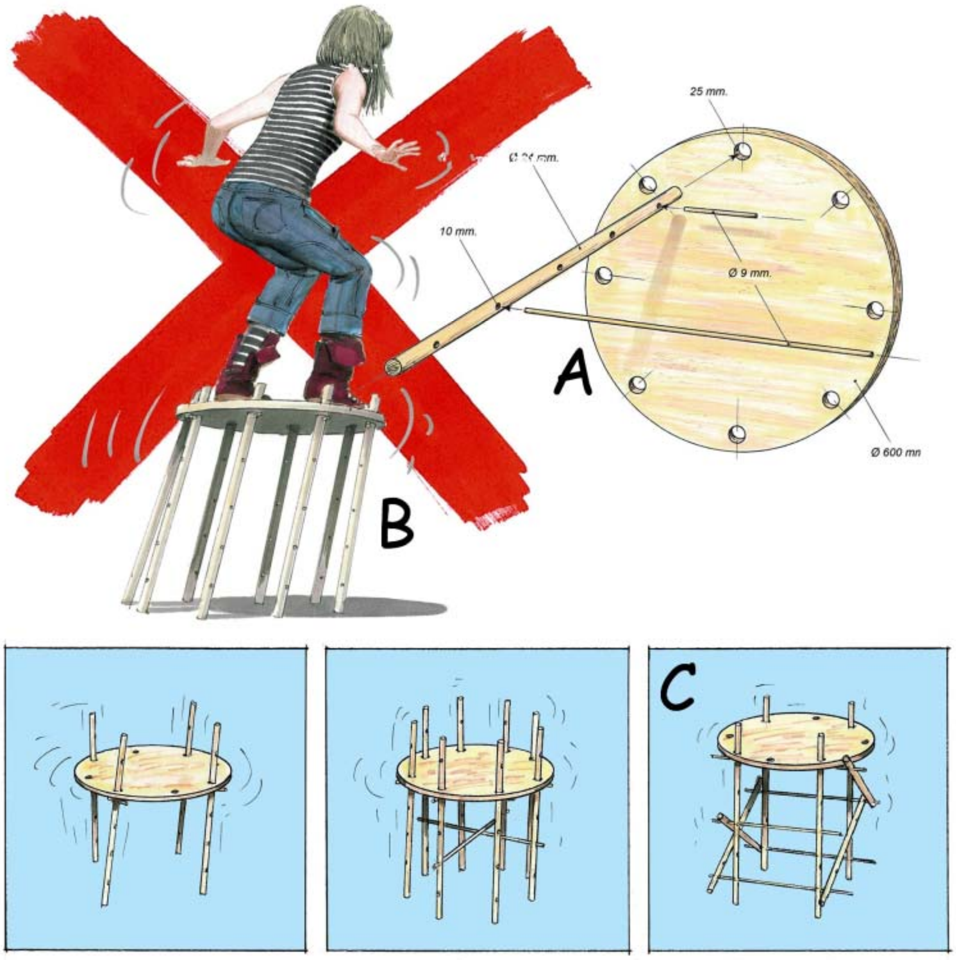

Figure 1: (A) Handstorm® Modular Building System parts; (B) Failure of the simple construction of disk and poles and (C) Remedying this by thoughtfully positioning a few connecting sticks.

The design and building process was monitored either by the first author (Cases A, B, & D) or by both the first and the second author (Case C). The process was either documented on video (Cases A, B, & D) or photographed (Case C). In all cases, only one video camera was used. In cases A and B, the first author recorded only the interesting activities of a group. In addition to preparing a written qualitative summary of the design and building process, the video recordings were analyzed quantitatively. The recording was broken up into 30-minute blocks, and the blocks were categorized and scored according to the following classes of activity: no activity, discussion, trying the connections of the MBS, construction according to initial design, improving the construction, testing the construction, and construction according to a new design (Table 1). The design activity that resulted from a failure was also explored (Table 2). Two types of failings were defined: innate failing (instability caused by moving or loading, and collapsing upon loading) and emotional failing (observing the success of the other group or losing the competition).

Case A: Postgraduates in competition

Participants: Two groups of 5 or 6 novice designers (3 females & 2 males, and 2 females & 4 males, respectively; aged 23–25 years). All had a MSc: four in Architecture (but no practical experience in the profession), one in Landscape Architecture, one in Innovation Management, one in Psychology, and four in Urban Design.

Situation: On October 26, 2004, an MBS assignment was organized as a competition between the two groups at the end of a class on the management of innovation processes in design groups, which is part of the postgraduate Architectural Design Management Systems program at Eindhoven University of Technology. No specific guidance was given, and no examples of structures were shown.

The design students were allowed 60 minutes to design and construct a platform that had to be as high as possible, incorporate the smallest number of building parts as possible, and be able to carry the weight of all members of the group at the same time (one person on each disk). The groups worked in the same room and could observe each other.

Case B: Primary school children at the university's open day

Participants: Mostly primary school children (50% males, 50% females, aged 6–14 years) and their parents at Eindhoven University of Technology's open day on October 3, 2004. The open day is an annual event that is heavily advertised beforehand. The Department of Architecture, Building and Planning organized the MBS event to show children both the constructional and the architectural side of its domain.

Situation: We asked the children to build a nice looking Idols™ platform that could bear the weight of one child. For this, 10 working stations were set up in a large hallway. Each working station was manned from 12:00 to 17:00 by an undergraduate Architecture student, whose job was to ensure the children's safety and security, and to take photographs after the task had been completed. The public, including other children, could freely walk in and out the hallway and from one working station to another. Only one group was allowed at each working station, but there was no time limit for task completion. Groups could have any size, and some were very large. In addition to the MBS, some extra materials were provided so that the children could beautify their platform, namely: sheets of colored cardboard, a pair of scissors, and drawing materials; sticks 1200 mm long to support the cardboard; and additional connecting materials (rope, rubber bands, paperclips and adhesive tape). A finished example was present for instruction and introduction purposes, as was a written description of the task (mainly for parents). Several colored posters advertising the task were hung on walls inside and outside the hallway. No oral guidance was given to the children, unless it was necessary to ensure their safety. In total, 81 platforms were completed. Two building trials were recorded on video and analyzed. Group I consisted of 3 boys aged 11–14 years, and Group II of 3 boys of about 10 years and 1 girl of 6 years.

Case C: Primary school children in a compulsory event

Participants: Thirteen primary school children (6 males, 7 females, aged 9–11 years) and their teachers at the AVS (association of school directors) conference in Nieuwegein, the Netherlands, during school hours on April 27, 2006.

Situation: The assignment and setup were similar to Case B, but only three working stations were supplied in a large room, where the platform building had to compete with nine other interesting technology activities. Paper clamps and textile sheets were added to the materials mentioned for Case B as additional beautifying and connecting supports. Pictures of completed platforms were shown. The children were instructed orally in aspects of strength and stability by the first author through the construction of three example platforms with increasing levels of stability and strength. The children were not allowed to leave the room during the event. Groups formed voluntarily. Four of these groups finished the assignment within an hour. At this event, MBS received second prize in the national innovation competition for primary education in technology (Kader Primair, 2006).

Case D: Graduates in competition

Participants: Two groups of six design students at Master's level (all males, aged 22–23 years) with Bachelor degrees in Civil Engineering and Architecture.

Situation: On October 17, 2006 an MBS assignment was organized as a competition between the two groups during a class that forms part of Eindhoven University of Technology's Construction Management and Engineering program. Each group was observed by three students. The assignment was the same as in Case A.

4. VALIDATION RESULTS

Postgraduates

Process: **Group I** first examined the building materials. No group leader came forward. The group started by making calculations to find out the best chance of winning with the supplied materials: greater height or fewer building parts.

After 35 minutes, the group completed building and tested the construction. The structure failed (Figure 2). The reactions of the group members to the collapse ranged from laughing, looking helplessly at the spectators, examining the (broken) MBS parts, and asking the lecturer whether the collapse was a normal part of this methodology, and why these tools were not more robust. However, immediately after the collapse, the group started to construct a completely different platform. This happened without much discussion among the group members. It seems as though their hands automatically knew what they should do. In just three minutes, the concept of a new platform was born; three minutes later, the platform passed the loading test (Figure 3). The group spent the remaining 10 minutes optimizing the construction by reducing the number of building parts without losing stability or strength.

Figure 2: The novice designers in Group I test their platform. It collapses, causing much hilarity among the group members, and leads to a new design

In **Group II,** an informal leader stood up within 30 seconds, and proceeded to introduce the flip-over board to tackle the design problem. During the whole session, this tool remained in use for a cumulative period of 4.5 minutes. The informal leader started to explain the design strategy to the lecturer 8 minutes later: the group had decided to use the long sticks as much as possible, to support a structure with 3 higher and 3 lower disks, and to use a pole for one extra disk. As soon as Group II saw that Group I had succeeded with another type of platform, they stood there abashed. They dismantled their own structure within 2 minutes, and within another 7 minutes they had built another one that could support the required weight (Figure 3). Since their structure was lower and contained more building parts, they were declared the losers. Eight minutes after the competition, two members of Group II realized a completely new concept using the group members as structural elements, thus increasing the height without using any extra wooden building parts (Figure 3).

Figure 3: Both Group I and Group II pass the weight test. Group I was the winner (A), Group II the loser (B)

Effect of failure: In **Group I,** the crisis caused by the collapse of the platform resulted in the prompt discard of the initial design concept, and the quick development, adoption, and execution of an innovative and better design.

In the case of **Group II,** the failure came from outside sources: First, from Group I (which they considered a sure winner), and second (after the competition), through the shocking event of having lost mercilessly.

Children at the open day

Process: **Group I** succeeded in building a weight-carrying platform within 11 minutes. However, one of the boys immediately criticized their own design by saying "It looks terrible!" The group members were also not satisfied with the stability and continued to add sticks to the structure until the wobbling ceased completely (Figure 4). During the whole building process, the group members kept up a lively discussion.

In the case of **Group II,** the boys did the building, while the girl worked on the decoration of the platform. There was no connection between the boys and the girl. The construction was dominated by a boy who whistled frequently, scolded the other boys, indicated that this or that did not work, pulled on sticks and poles, went away, came back again, and gesticulated a lot when things did not go his way. Wobbling during testing was tackled with rope and elastic bands (Figure 4).

Effect of failure: In both cases, the wobbling of the construction, when observed, led only to the addition of more building or connecting materials, and not to a fundamental change in design.

Figure 4: The Idols™ platforms of the two groups

Figure 5: An Idols™ platform under construction and one completed at the AVS conference

Children at the compulsory event

Process: The MBS working stations did not attract sufficient attention, and the first two authors had to actively motivate children to start and complete the construction assignment. The other nine activities in the room were more rewarding for most children. One group that completed the platform, covered it completely with colored cloth before the photograph was taken. The children really experienced themselves as Idols™ (Figure 5).

Effect of failure: None; the attendants solved all the problems that arose.

Graduates

Process: **Group I** spent the first 10 minutes discussing the assignment and designing some solutions with the help of a flip-over board. By constructing the initial design, the group realized that a simple MBS platform is not stabile by itself. They dismantled it and started to construct a new one. This happened 3 times within 10 minutes. The group constantly tested the construction for stability by loading it. The fourth attempt succeeded, and they decided to optimize the construction. Two shorts sticks were replaced by one long stick.

The group finished the assignment within the time limit. The observers noted that the graduates did not organize the process and did not spend much time analyzing the problem. One of the observers told the lecturer: “If I were a member of the group, I’d have done the same.” When the assignment was finished, the group found time to reflect on the strategy: A smaller number of parts is more important than the height attained. Everybody in the group was involved in the process.

Group II also spent 10 minutes discussing a solution; they used a note pad and did not really collaborate. They worked for about 15 minutes, and during that time they hardly tested for stability. After that, they decided to dismantle the construction, probably influenced by the results of Group I. Their second try succeeded after 20 minutes, and they decided to optimize the construction by placing another disk on top. This caused a lot of stability problems that were not solved within the 60-minute time limit. When the construction was subsequently tested, it collapsed. The observers reported that the group members designed individually and did not share their ideas or collaborate. The design arose not through discussion, but by trial and error.

Before the competition started, the students explained why they had chosen the Master's program in Construction Management and Engineering. Most of them had been attracted by organizing and managing the whole construction process. The building experience confronted them with the meaning of such management. As the observers commented, they had hardly organized or managed the process. This recognition startled them.

Effect of failure: In **Group I**, instability led to four designs. **Group II** felt that the other group was more successful, and thus started a new design. For one reason or another, the group did not test their work within the given time. Were they afraid that the construction would collapse?

Group I was proud to win the bottle of wine, but **Group II** was not amused – and returned the bottle of lemonade.

Quantitative analysis

The four design groups of graduate/postgraduate students had lengthy discussions to attain consensus on a design concept before they started to build. They sometimes stopped, perhaps to think things over. The groups of children simply started and did not stop building until they had finished. Children tested their structure when they thought it was ready, and simply added more building and connecting materials if the platform wobbled or threatened to collapse. The student groups reacted differently to the threat of a failure: They adopted new, and sometimes innovative, designs (Tables 1 and 2).

Table 1: Frequency of activities (30-minute blocks in the video recording) during design and building with Handstorm® Modular Building System in groups of postgraduate design students (A), primary school children (B), and graduates (D). In Cases A and B, only the interesting 30-minute blocks were recorded at the discretion of the first author.

Activity	**Frequency in %**					
	A_I	**A_{II}**	**B_I**	**B_{II}**	**D_I**	**D_{II}**
No activity	2	2	0	0	23	4
Discussion	17	20	0	4	24	23
Trying connections	4	5	0	0	3	5
Constructing initial design	11	27	44	29	3	17

Improving the construction	5	0	0	13	8	11
Testing the construction	11	3	5	11	9	7
Construction to new design	13	7	0	0	28	32
Not recorded 30-minute blocks	37	36	51	43	3	3
Total no. of 30-minute blocks	103	101	61	56	119	120
Total duration of the experiment	51'30''	50'30''	30'30''	28'	59'30"	60'

5. DISCUSSION

The teaching objective of experiencing both innate and emotional failure as a motivator for innovative design was met by the graduates and postgraduates, but not by the primary school children. It is obvious that the absence of a problem analysis stage in the case of the children designers (they simply discussed matters), is related to their developmental stage (Piaget, 2006). An external motivator, such as the aim of winning, is needed as a starter, with internal (innate) failure stress as a sustainer.

Table 2: Responsive activities after perceived failures

Group	Failure description	Responsive activity	N
A_I	Collapse upon loading	Constructing to new design	1
	Losing the competition	Improving the construction	1
A_{II}	Observing success other group	Constructing to new design	2
	Observing success other group	Constructing to new design *	
B_I	Instability	Improving	1
B_{II}	Instability	Improving	1
D_I	Instability	Constructing to new design	4
	Instability	Constructing to new design	
	Instability	Constructing to new design	
	Instability	Constructing to new design	
	Losing the competition	Improving the construction	1
D_{II}	Observing success other group	Constructing to new design	1
	Instability	Improving the construction	1
	Losing the competition	Improving the construction	1
	Collapse upon loading *	No activity	

The absence of failure stress, however, is most likely caused by another mechanism. The children had only one innate failing risk to attend to: a collapsing platform. Enough spare building and connecting parts were available to surmount any instability of the platform, and there was no competition with other groups. The university students, however, faced a much more complex task. Requirements such as reducing the number of building parts and constructing higher, are conflicting. Choices had to be made, and the wrong one would lead to the collapse of the platform or to losing the competition. The introduction of complexity through conflicting requirements and the objective to win a competition turns the Handstorm® MBS into a dependable and "real world" teaching tool.

The question remains why this effect is not readily obtained with other MBS used in teaching, such as LEGO® SERIOUS PLAY™, [4] which also involve competing requirements. Design teams in architecture and building are, however, project organizations with a short life time that ends upon the completion of the designing project, while teams of managers who develop business strategies are expected to execute their own strategic plans for years to come. Therefore, in teaching business innovation, the focus is not on the innovation as such, but on building a sustainable team. Learning through failure could damage cohesion and social bonding in the long run, or might demotivate group members from tackling the task at hand.

For the project organization of design teams, the Handstorm® MBS elicited collaborative design driven by failure stress in novice designers who had to cope with a number of partially conflicting requirements. Primary school children, who only had to cope with the shocking event of the collapse of their platforms, did not show such innovative behavior. The children followed the optimizing path in the design and construction process. We conclude that MBS that have a high innate risk of structural collapse, such as the Handstorm® MBS, are tools for teaching design teams the value of failure stress in design, in order to prevent failures in the final construction of real-life building projects. This brings Gore's (2003) "serious play" to the teaching studio, and we agree with Gore that these lessons "stick" and are transferable.

6. CONCLUSIONS

As an educational tool, the Handstorm® MBS is a valid motivator for the use of failures in collaborative design. It makes the student more aware that failures help the team to construct according to newly developed designs. When the stress of the failure is too low or too high, it kills motivation.

The lessons derived from the cases will lead to the further development of the Handstorm® MBS in order to make it suitable for extensive implementation. We will consider different shaped disks, more holes in the parts, coloring the parts, etc., so as to increase the number of possible types of assignments.

At a higher level, we believe that the concept of failure is a tool to break designers out of their established pattern during collaborative design meetings. It fits all kinds of problem solving and creativity thinking techniques.

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ARE ACTIVITY DISTRIBUTION TYPES IMPORTANT IN PERT?

Miklós Hajdu PhD
Head of Institute of Construction Management Ybl Miklós Faculty of Architecture and Civil Engineering, Szent István University, Budapest, Hungary, hajdu.miklos@ybl.szie.hu

Abstract

The Program Evaluation and Review Technique (PERT) is the first modern technique of project management that is able to preserve the logic created by the planners. As a stochastic network technique, original PERT model assumes PERT beta distribution for the distribution of activity durations. Many critiques have been addressed to this hypothesis since the beginnings. Researchers have introduced many new distributions like lognormal, double truncated normal, triangular, Parkinson distribution, etc. arguing that they are either better in modeling the real distribution or easier to handle from a mathematical point of view.

In this paper, we examine the effect of using different activity distributions on the distribution of the project duration. Beta, triangular and uniform distributions were used on activities and the distribution of the project durations were then compared. Results show that the differences in the distribution of the project duration caused by using different activity distributions are not considerable compared to the differences caused by the inaccuracy of the PERT three-point estimations. Numerous artificial and real life sample projects were used to prove this allegation. Monte Carlo analysis was used to create the probabilistic distributions of the projects.

Keywords: PERT, distribution of project duration, Monte Carlo simulation.

1. AN OVERVIEW OF THE PROGRAM EVALUATION AND REVIEW TECHNIQUE

1.1 Introduction

In this paper, we examine the effect of the application of different activity distributions on the distribution of the project duration in PERT networks. We prove – using both artificially created sample projects, and real life infrastructural projects – that the difference between the results caused by different activity distributions is not significant compared to what a 10% inaccuracy in the estimation of the most likely, optimistic and pessimistic values of the activities can cause to the distribution of the project duration.

The paper is organized in the following way:

- Section 1 shortly summarizes the basic concept of PERT in order to make the paper understandable for those who are not experts of PERT.
- Section 2 gives an overview of the main criticisms addressed to PERT.
- In Section 3 the effects of the different activity distributions on the distribution of the project distribution are shown.
- Section 4 provides the conclusions of the research and recommendations for further research.

1.2 Introduction to PERT

The original Program Evaluation and Review Technique (PERT) [1] is an activity-on-arrow network with one start and one finish event, which represent the beginning and the end of a project. To accomplish the project, certain activities must be carried out according to a given pre-defined sequence. This logic is depicted by a directed, acyclic graph in which the vertices of the graph represent the events, while the arrows represent the tasks to be performed. An event occurs when all preceding activities have been completed; only then can the succeeding tasks start. In this way, the event is used for expressing logical dependencies between activities.

In a PERT network, activity durations are defined by stochastic variables that are assumed to be independent of each other. The distribution of the activity durations follows a so-called PERT-beta distribution. The formula of the beta function is shown below (Eq. 1). In the formula, α and β are the parameters of the beta distribution; and a and b are the endpoints of the domain of x. Outside the interval, $f(x)=0$. Possible density functions of the beta distribution for which $a=0$ and $b=1$ are shown in Figure 1. The distribution is identified as PERT-beta if the α and β parameters of Eq. (1) are greater than 1 ($\alpha>1$ and $\beta>1$). This ensures that $f(x)$ has one maximum, and $f(x)$ tends to zero at the endpoints of the domain $f(a)=f(b)=0$ (Figure 2).

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(x-a)^{\alpha-1}(b-x)^{\beta-1}}{(b-a)^{\alpha+\beta-1}}, \qquad a<x<b, \qquad \alpha,\beta>0 \qquad Eq.(1)$$

The mean $(\overline{x})$ and variance (σ_x^2) of the activity durations in PERT are defined according to Eq. (2) and Eq. (3), respectively:

$$\overline{x} = \frac{a+4m+b}{6} \qquad Eq.(2)$$

$$\sigma_x^2 = \left(\frac{b-a}{6}\right)^2 \qquad Eq.(3)$$

where a, m and b are subjective values, determined by a specialist, representing the optimistic (a), the most likely (m) and the pessimistic (b) durations of the activity (see Figure 2). The process of defining these subjective values is called the PERT three-point estimation method.

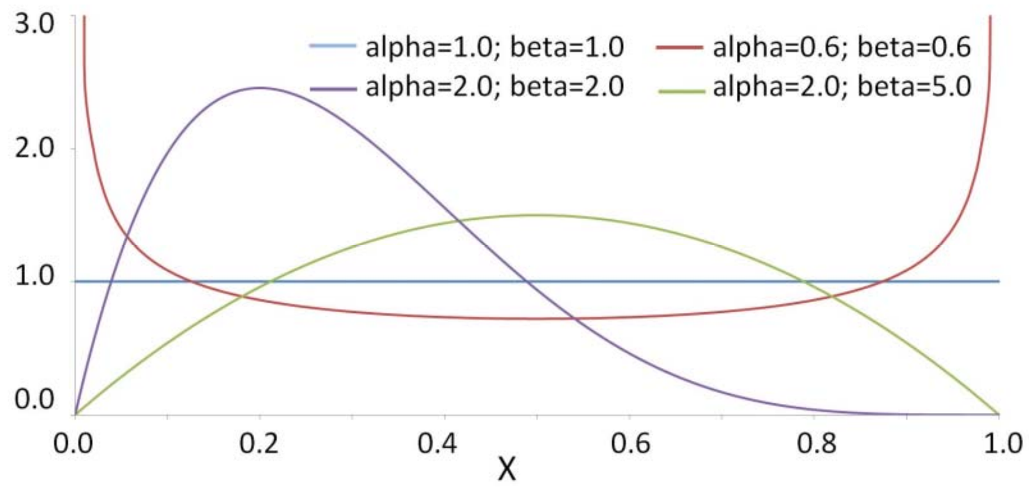

Figure 1: Possible density functions of the standardized beta distribution

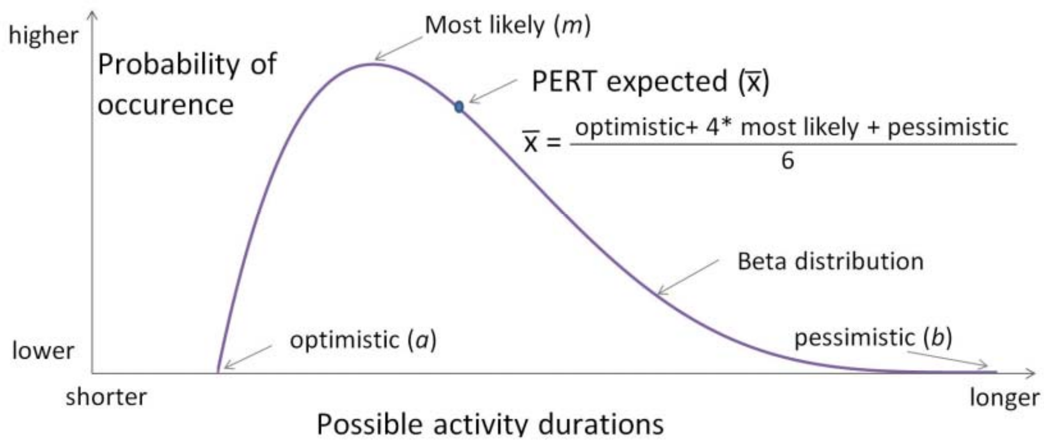

Figure 2: Typical density function of the PERT-beta distribution

The main goal of the PERT analysis is to create the distribution of the project duration.

According to PERT theory, the project duration follows a normal distribution, with the mean being the result of time analysis based on activity mean durations ($\overline{x}$) and the variance being equal to

$$\sigma_{PD}^2 = \sum_{x \in CP} \sigma_x^2 \qquad Eq. (4)$$

where σ_{PD}^2 is the variance of the distribution of the project duration (PD) and *x* represents the activities on the critical path (CP). These calculations are based on the central limit theorem of mathematical statistics.

The theoretical optimistic and pessimistic project durations, that is, the lower and upper bounds of the distribution of the project duration, can be defined as the results of time analysis performed with the optimistic and pessimistic values, respectively.

2. REVIEWS AND DEVELOPMENTS OF PERT

PERT has received a great deal of criticism since its "birth". These critiques can be classified into the following five classes:

- critiques of the three-point estimation
- critiques of the proposed activity distribution
- critiques of the independence of the activities
- critiques of the result of the PERT calculation
- critiques about omitting activity calendars from the PERT theory

One of the early criticisms of PERT, as noted by Clark [2] and Sasieni [3], was that the means (Eq. 2) and the variances (Eq. 3) of the activity durations cannot be obtained from Eq. 1 without making further assumptions. Earlier studies focused on either the justification of Eq. 2 and Eq. 3 or on developing new means and variances for the activity probability density function. Keefer & Brodily [4] reviewed the existing methods, and Farnum & Stanton [5] showed that there are theoretical grounds for using Eq. 2 and Eq. 3 within a specific range (Eq. 5) of modal values.

$$a + 0{,}13(b - a) \le \bar{x} \le a + 0{,}87(b - a) \qquad Eq.(5)$$

The above-mentioned works and other approximations developed by several researchers, e.g., [6], [7], show that this issue has still not been solved.

Proposals for other estimation methods based on fractiles of the beta distribution were presented by researchers such as Meredith at al. [8]. Pearson at al. [9]. They demonstrated a definitively better approximation of the mean and the variance, assuming that expert estimations are more precise when estimating the fractiles (probabilities) of the pre-defined activity durations.

Use of the beta distribution has been criticized by many researchers. During recent decades, researchers have suggested the use of many different distributions other than beta, like the doubly truncated normal distribution [10], the log-normal distribution [11], the mixed beta and uniform distribution [12], the triangular distribution [13] and the Parkinson distribution [14], among others. Some authors – among them Clark [2] – argue against the introduction of new probability distributions into PERT. According to him: "*The author has no information* *concerning distributions of activity times; in particular, it is not suggested that the beta or any other distribution is appropriate.*" In the same line of thinking, Kamburowski [15] stands by the applicability of the original assumptions (Eq. (2) and Eq. (3)) and opposes those who believe that a different distribution must be introduced. He argues that due to the significant uncertainty and imprecision reflected in the estimates, the precision that we can achieve using Eq. (2) and Eq. (3) is satisfactory. The author strongly agrees with these authors. One of the main purposes of this paper is to justify the above quotation by showing that the usage of different distributions does not result in considerably great differences in the distribution of the project duration, or at least they are smaller than the difference caused by a 10% inaccuracy in the estimation of the most likely values of the activities.

Those who applied PERT found out quite early on that the value PERT yields as the expected project duration is too optimistic. The reason for this trend is that the PERT assumption for the project duration is precise – due to the central limit theorem – only in cases in which there is exactly one critical path in the network. However, this is rarely the case; there are usually many parallel critical paths in the network. In such instances, the distribution of the project duration is determined by the distribution of the maximum of the different critical paths [16]. Hajdu [17] has created a simple network with ten parallel and identical paths, and had shown using Monte Carlo simulation that the probability for finishing the project in this case within the expected value defined by the PERT calculations is less than 1%.

Solutions for determining the distribution of the project duration can be divided into three groups according to the classification by Adlakha [20] and Elmaghraby [21], from estimations [18] [26] [27], through Monte Carlo simulation [19] [23] [24], [25] to analytical solutions [22]).

Recently Hajdu [17] has shown the dramatic effects of activity calendars to the distribution of the project duration. He has shown using a simple one-chain 10 activity PERT network, with uniform distribution on all the activities, that activity calendars can distort the distribution of the project duration to such an extent which questions the use of the original PERT calculations. Some unusual distributions for project duration can be seen on Figure 3. Minor changes in the calendars have caused the differences between the cases.

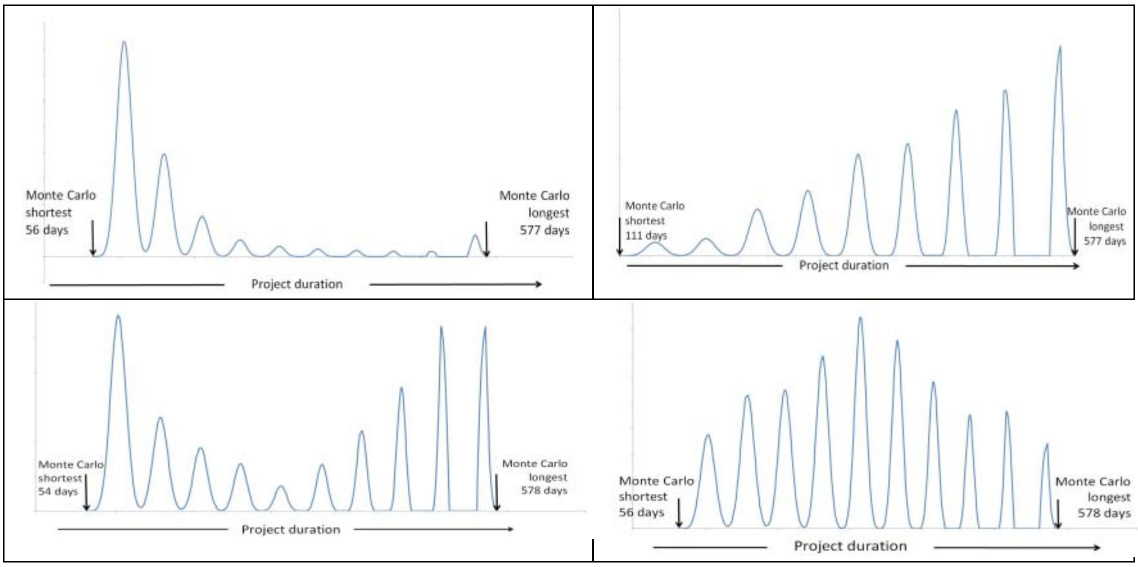

Figure 3: Different distribution of the project duration caused by minor changes in activity calendars

3. THE EFFECT OF ACTIVITY DISTRIBUTIONS TO THE PROJECT DURATION

In this section three artificially created sample networks, and a real life network of an infrastructural project will be examined. In each case we perform a Monte Carlo simulation assuming that

a) all activities follow a PERT beta distribution, which distribution is defined by the original three-point estimation,
b) all activities follow a PERT beta distribution with 10% smaller values for all activity durations (optimistic, most likely, pessimistic) in case of all activities.
c) all activities follow a PERT beta distribution with 10% greater values for all the activity durations (optimistic, most likely, pessimistic) in case of all activities.
d) all activities follow a triangular distribution, using the data defined by the three-point estimation of a)
e) all activities follow a uniform distribution with the optimistic and pessimistic activity times obtained from the three-point estimation

Analysis is performed by ProJack, a general purpose scheduling tool that can perform Monte Carlo simulation. (www.projackmanager.com)

3.1 Sample #1

The first – artificial – sample project can be seen on Figure 4. This is a one-chain network, where the same attributes are applied for all the activities in case of a), d) and e), that is a=60 days, m=100 days, b=150 days, 10% smaller values in case of b), and 10% larger values in case of c) for all activities. Activities follow PERT-beta distribution in case of a), b) and c). Activities follow triangular distribution in case of d), and uniform distribution in case of e).

Data for the different cases can be seen in Table 1.

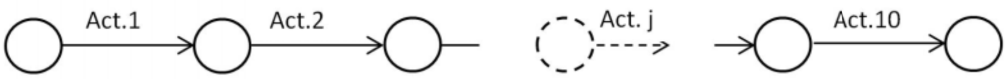

Figure 4: Sample project #1.

	Optimistic (a)	**Most likely** (m)	**Pessimistic** (b)	**Distribution** Type	**Legend of** Fig. 5
Case **a)**	60 days	100 days	150 days	PERT Beta	
Case **b)**	54 days	90 days	135 days	PERT Beta	
Case **c)**	66 days	110 days	165 days	PERT Beta	
Case **d)**	60 days	100 days	150 days	Triangular	
Case **e)**	60 days	100 days	150 days	Uniform	

Table 1: Durations and distributions for cases a) – e) of Sample #1 - #3

Figure 5 shows the results. It can be seen, that the different activity distributions cause smaller differences in the distribution of the project duration than the difference caused by a +/- 10% percent difference in the three-point estimation.

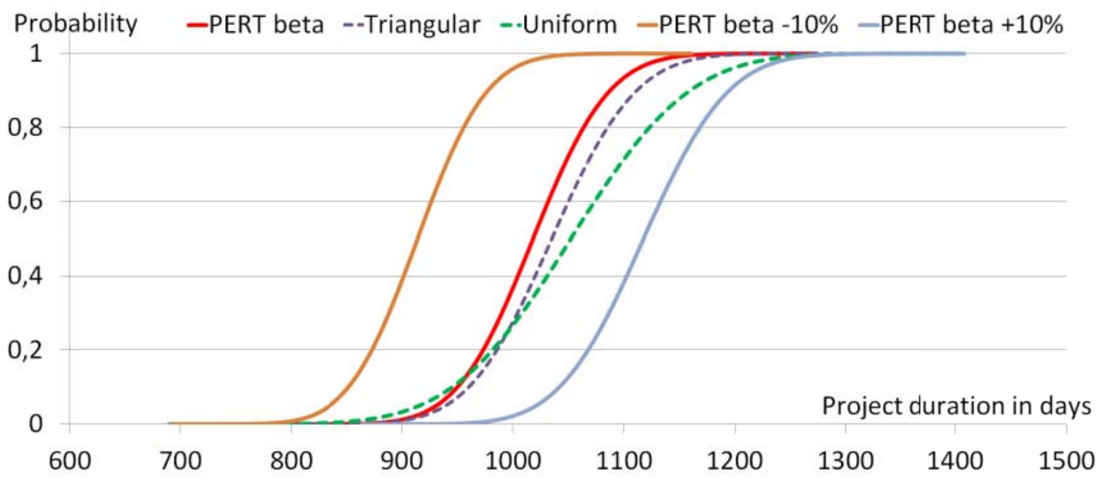

Figure 5: Distributions for Sample #1 cases a) –e)

3.2 Sample #2

The second – artificial – sample project can be seen on Figure 6. This network consists of ten parallel paths, where each path is identical to the one-chain network of Sample #1. The same attributes are applied for all the activities in case of a), d) and e), that is a=60 days, m=100 days, b=150 days. In case of b), the values are 10% smaller, while in case of c), they are 10% larger for all activities. Activities follow PERT-beta distribution in case of a), b) and c). Activities follow triangular distribution in case of d), and uniform distribution in case of e).

Data for the different cases can be seen in Table 1.

In order to ensure the requirements for the one start and one finish event, a new start and a new finish event have been included, and paths have been connected to them. (Figure 6)

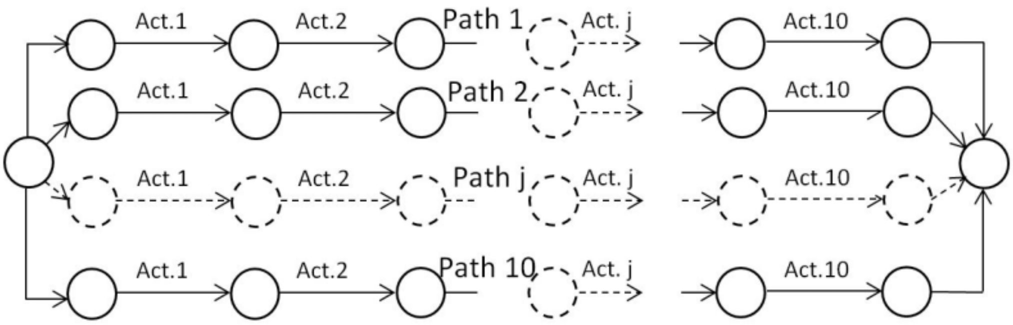

Figure 6: Sample project #2.

Results can be seen on Figure 7. Due to multiple critical paths, the distance between cases b) and c) is considerably smaller than the difference between the same cases of Sample #1. Despite this, cumulative distributions derived from triangular and uniform activity distributions remain between the distribution of b) and c). It can be seen that the different activity distributions cause smaller differences in the distribution of the project duration than the difference caused by a +/- 10% percent difference in the three-point estimation. It is interesting to see that uniform distribution results in a more pessimistic distribution than the PERT Beta with the original (60,100,150 days) estimation. This is due to the fact that in case of many parallel paths, the path with the maximum length will define the project duration.

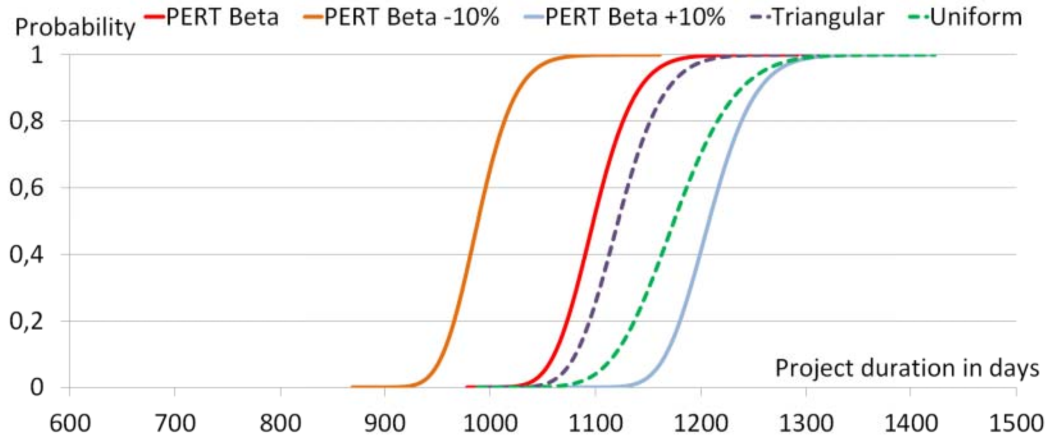

Figure 7: Distributions for Sample #2 cases a) –e)

3.3 Sample #3

The third – artificial – sample project can be seen on Figure 8. This network is a modification of Sample #2, and simulates a case when critical paths are intertwined. The fifth activity of all paths is the same, therefore 100 different paths exist in this network and all of them can candidate for being critical. Durations are the same as they were in the previous samples. Data for the different cases can be seen in Table 1.

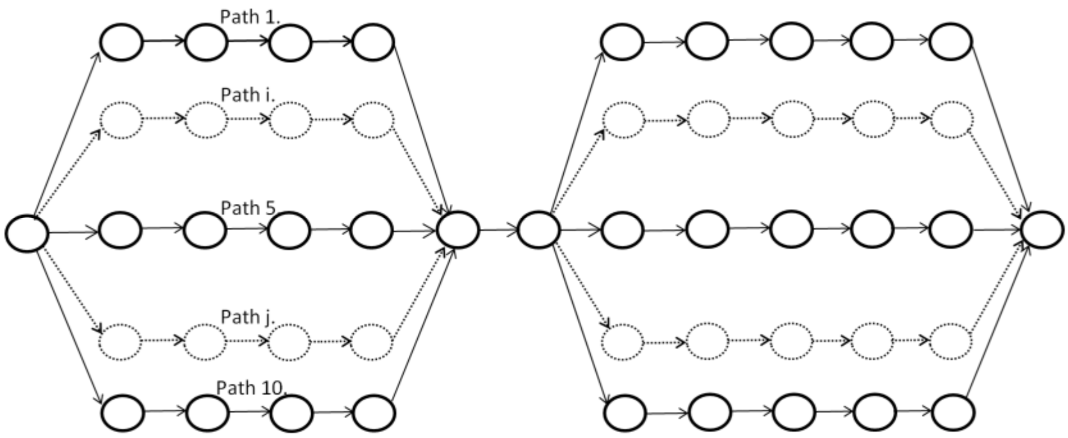

Figure 8: Sample project #3

Results can be seen on Figure 9. Due to the multiple possible critical paths distance between cases b) and c) is the smallest of all the samples. The cumulative distributions derived from triangular and uniform activity distributions remain between the distribution of b) and c), except in the P(X)>0,99 domain.

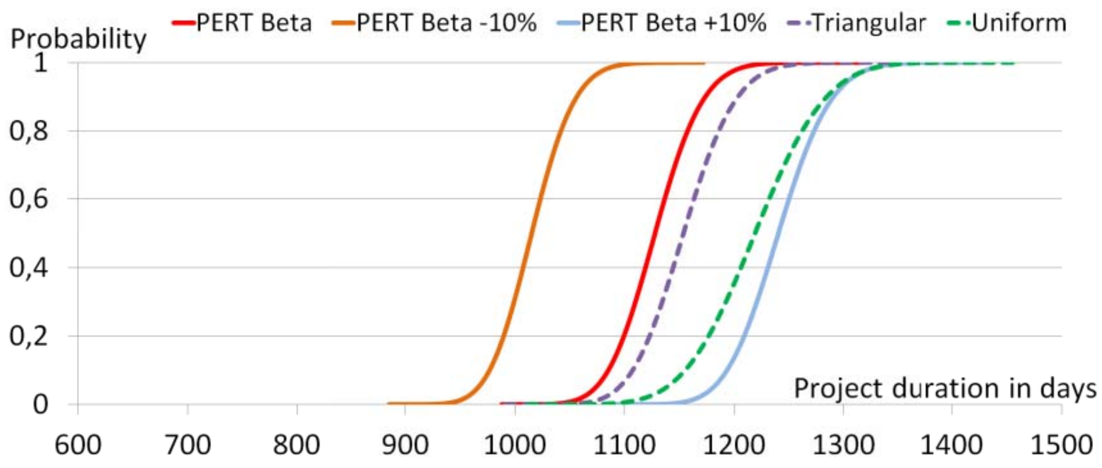

Figure 9: Distributions for Sample #3 cases a) –e)

3.4 Sample #4

The fourth sample project is a highway bridge construction project.

The project chosen for testing is a construction of a bridge over the river Danube, with the connecting roads at the two ends, is being built in Budapest, Hungary. The start of the project was February, 2006 the planned finish was September, 2008. The project was finished according to the deadline of the first baseline plan.

The total length of the bridge is 1862 m. Structurally, it is composed of five parts with the following bridge spans:

- Left quayside (Pest) inundation area bridge: 37 m + 2*33 m +45 m
- Main Danube-branch bridge: 145 m + 300 m + 145 m
- Szentendrei island inundation are bridge: 42 m + 11* 47 m
- Szentendrei Danube-branch bridge 94 m+ 144 m + 94 m
- Right quayside (Buda) inundation area bridge: 43 m + 3*44 m + 43 m

Figure 10: Main Danube-branch Bridge: Bird'- eye view.

The contracted fee was around €260 million.

Client was represented by the National Infrastructural Development Agency (NID). NID had very strict requirements regarding project planning and monitoring, and demands that all contracted partners fulfill their regulations in these fields. The reason for this was that NID managed not only the project but the whole portfolio; therefore projects had to be managed and handled in a standardized way. It can be stated that due to the strict requirements of the client, the quality of the baseline plans prepared by the contractors were high above the average construction industry standards.

The baseline plan that was the basis of our work was made in 2006, and was comprised of 1316 activities and 1420 logical relationships. In the baseline plan there was one critical path with the length of 938 days. Four different calendars were used in the network.

The plan was based on the Precedence Diagramming Method, and time constraints were also used in the network. During the examination of this project we followed the same methodology used in the case of the artificial samples. First we assumed that all the activities follow a PERT beta distribution with 40% smaller optimistic and 50% greater pessimistic values compared to the most likely durations. Most likely durations were the activity durations of the deterministic network. Next we assumed that the activity distributions are the same and 10% inaccuracy happened during the three-point estimation, so all durations were decreased by 10%. Thirdly, we increased the activity durations by 10%. In case of d) the original estimations of case a) were used but we applied triangular distribution for all of the activities. In case of e) the original estimations were used with uniform distributions. These cases are shown in Table 2. (*t* stands for the original activity duration used in the Precedence Diagramming network.)

	Optimistic (a)	**Most likely (m)**	**Pessimistic (b)**	**Distribution Type**	**Legend of Fig. 5**
Case **a)**	m - 40%	*t*	m + 50%	PERT Beta	
Case **b)**	m - 40%	0,9*t*	m + 50%	PERT Beta	
Case **c)**	m - 40%	1,1*t*	m + 50%	PERT Beta	
Case **d)**	m - 40%	*t*	m + 50%	Triangular	
Case **e)**	m - 40%	*t*	m + 50%	Uniform	

Table 2: Durations and distributions for cases a) – e) of Sample #4

Results shown in Figure 11 are essentially similar to the results of the artificial samples. The function of the uniform distribution goes outside the interval determined by cases b) and c), however, this is only true for a very short section and the difference is really small. This deviation is so insignificant that the original assumption, according to which the 10% error occurring in the three-point estimation causes greater differences in the distribution of the project duration than the application of various activity distributions, does not have to be rejected.

It is worth having a look at the distribution function of b), whose shape is unusual; therefore the density function corresponding to the distribution is also shown. (See Figure 12)

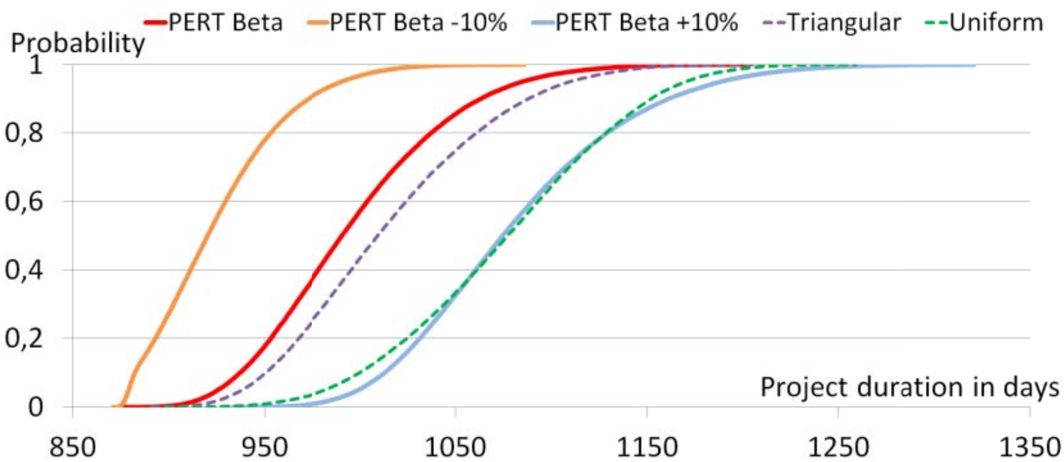

Figure 11: Distributions for Sample #4 cases a) –e)

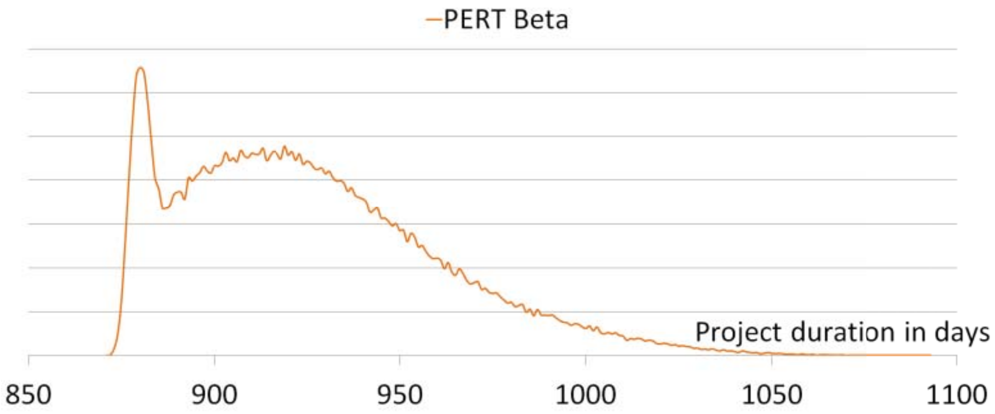

Figure 12: Density function corresponding to the distribution of case b)

The dramatic deviation from the usual shape of the project duration is the result of the combination of the factors below:

- application of different activity calendars
- application of time constraints in the plan (ie, must start on or later… etc)
- and the use of Precedence Diagramming Method.

5. CONCLUSIONS AND SUGGESTIONS

As it is shown in Chapter 2, introduction of different activity distributions plays an important part in the multidirectional development of PERT. However, the practical use of these new distributions has rarely been the subject of a detailed investigation. This issue divides the researchers of this field. Some authors – among them Clark [2] – argue against the introduction of new probability distributions into PERT, while others apply new distributions, and try to convince the scientific community that introducing this or that distribution has practical use for planners.

This paper have tried to add some new aspects to this debate, and investigated this issue from a practical point of view. It has been examined through various sample projects how the application of different activity distributions affects the results compared to the use of the PERT beta distribution. Both the artificial and the real-life projects have shown that +/- 10% difference in the PERT three-point estimation causes greater deviation than the application of different activity distributions. It could be concluded that the usage of different activity distributions does not result in significant differences from a practical point of view. The precision of the three-point estimation plays a much more important role in determining the distribution of the project duration.

The research has to be continued. The results have to be tested in case of other activity durations and many more practical projects.

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EFFECTS OF ACTIVITY CALENDARS IN PERT NETWORKS: CASE STUDIES

Miklós Hajdu PhD
Head of Institute of Construction Management, Ybl Miklós Faculty of Architecture and Civil Engineering, Szent István University, hajdu.miklos@ybl.szie.hu

Abstract

The Program Evaluation and Review Technique (PERT), was developed in 1957. Its popularity has slowly faded after the first decade due to the many and only partially solved critiques. PERT has been criticized for the proposed (beta) distribution of the activities, the three-point estimation method, the assumption of task independence and the assumed distribution of the project duration. Developments and generalizations surfacing the succeeding years and decades have been mostly aimed at resolving these issues. Recently a new critique has been addressed to PERT: it has been shown that omitting activity calendars from the model can cause such a dramatic change in the distribution of project duration which questions the original PERT calculations in its basics. These studies have used artificially created samples. In this paper, real life case studies are used to study the effects of activity calendars on project duration. Real life projects add a new aspect to be studied when dealing with activity calendars: time constraints. Three real life projects are examined. All of them are using different activity calendars, and time constraints. Results are as dramatic as they were with artificially created projects, and emphasize the original statements, that PERT calculations cannot be used when different activity calendars are applied in the network. In the absence of analytic solutions, a robust tool performing Monte Carlo simulations has been used for calculations.

Keywords: PERT, distribution of project duration, activity calendars, Monte Carlo simulation.

1. AN OVERVIEW OF THE PROGRAM EVALUATION AND REVIEW TECHNIQUE

1.1 Introduction

In this paper, we examine the effect of activity calendars on the distribution of the project duration in PERT networks. We prove – using an artificially created sample project – that the original PERT methodology, which assumes normal distribution for the project duration, cannot be used, due to the distorting effects of activity calendars.

The paper is organized in the following way:

- Section 1 shortly summarizes the basic concept of PERT.
- Section 2 shows the effects of activity calendars on the distribution of the project duration using an artificially created project.
- Section 3 shows the effects of activity calendars on the probability distribution of the project duration in case of real life projects.
- Section 4 provides the conclusions of the research and recommendations for further research.

1.2 Introduction to PERT

The original Program Evaluation and Review Technique (PERT) [1] is an activity-on-arrow network with one start and one finish event. These two events represent the beginning and the end of a project. The logic of the project is depicted by a directed, acyclic graph in which the vertices of the graph represent the events, while the arrows represent the tasks. An event occurs when all preceding activities have been completed; only then can the succeeding tasks start.

Activity durations are defined by stochastic variables that are assumed to be independent of each other. The distribution of the activity durations follows a so-called PERT-beta distribution. The formula of the beta function is shown below (see Eq. (1)). In the formula, α and β are the parameters of the beta distribution; while a and b are the endpoints of the domain of x. Outside the interval, $f(x)$=0. The distribution is identified as PERT-beta if the expected value of the distribution and its variance can be defined according to Eq. (2) and Eq. (3). The a and b values are subjective values, determined by a specialist, representing the optimistic (a) and the pessimistic (b) durations, as well as m the most likely value of the duration of the activity (see Figure 1). The process of defining these subjective values is called the PERT three-point estimation method.

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \; \frac{(x-a)^{\alpha-1}(b-x)^{\beta-1}}{(b-a)^{\alpha+\beta-1}}, \qquad a < x < b, \qquad \alpha, \beta > 0 \qquad Eq.(1)$$

$$\overline{x} = \frac{a + 4m + b}{6} \qquad Eq.(2)$$

$$\sigma_x^2 = \left(\frac{b-a}{6}\right)^2 \qquad Eq.(3)$$

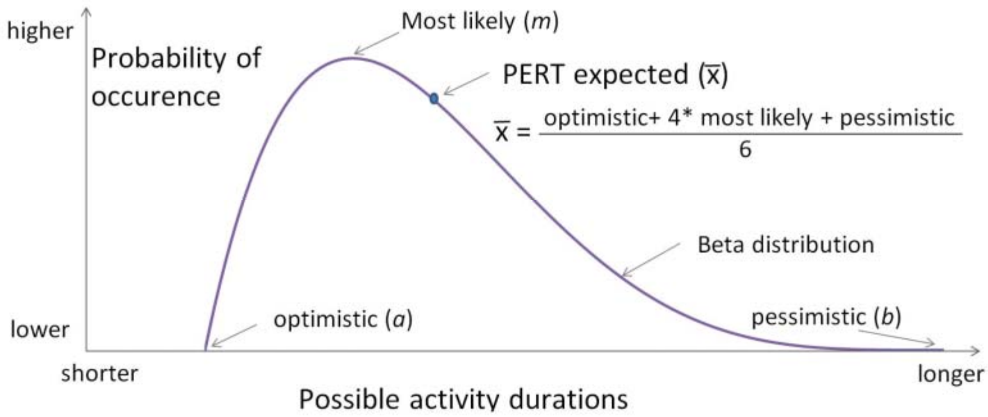

Figure 1: Typical density function of the PERT-beta distribution

The main goal of the PERT analysis is to create the distribution of the project duration.

According to PERT theory, the project duration follows a normal distribution, with the mean being the result of time analysis based on activity mean durations ($\overline{x}$) and the variance being equal to

$$\sigma_{PD}^2 = \sum_{x \in CP} \sigma_x^2 \qquad Eq.(4)$$

where σ_{PD}^2 is the variance of the distribution of the project duration (PD) and *x* represents the activities on the critical path (CP). These calculations are based on the central limit theorem of mathematical statistics.

The theoretical optimistic and pessimistic project durations, that is, the lower and upper bounds of the distribution of the project duration, can be defined as the results of time analysis performed with the optimistic and pessimistic values, respectively.

PERT has received a great deal of criticism since its "birth". These critiques can be classified into four classes, as follows:

- critiques of the three-point estimation [2],[3],[4],[5]
- critiques of the proposed activity distribution [6],[7],[8],[9], [10], [11], [12]
- critiques of the optimistic result of the PERT calculation [13],[14],[15],[16], [17], [19],
- critiques about omitting activity calendars [20].

In the following section, we will focus only on the last class of critiques that is the effects of activity calendars on the distribution of project duration.

2. EFFECTS OF ACTIVITY CALENDARS ON THE DISTRIBUTION OF THE PROJECT DURATION

Recently, the dramatic effects of activity calendars on the distribution of the project duration have been shown by Hajdu [20].

To illustrate this he has used a simple artificially created PERT network that can be seen on the figure below (Fig. 2).

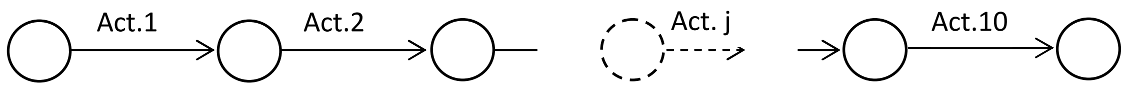

Figure 2: Sample PERT network (see [20])

The optimistic, most likely and pessimistic durations are 5 days, 10 days and 15 days, respectively, for all activities. All activities follow a uniform distribution. Non-working periods are assigned to each activity. Apart from that, work is allowed 7 days per week. Non-working periods are created in a way that the difference between the finish of a non-working period of an activity and the start of the non-working period of the consecutive activity is around 10 days, while the lengths of the non-working periods are considerably longer. (See Fig. 3) The project starts on the first day of the year.

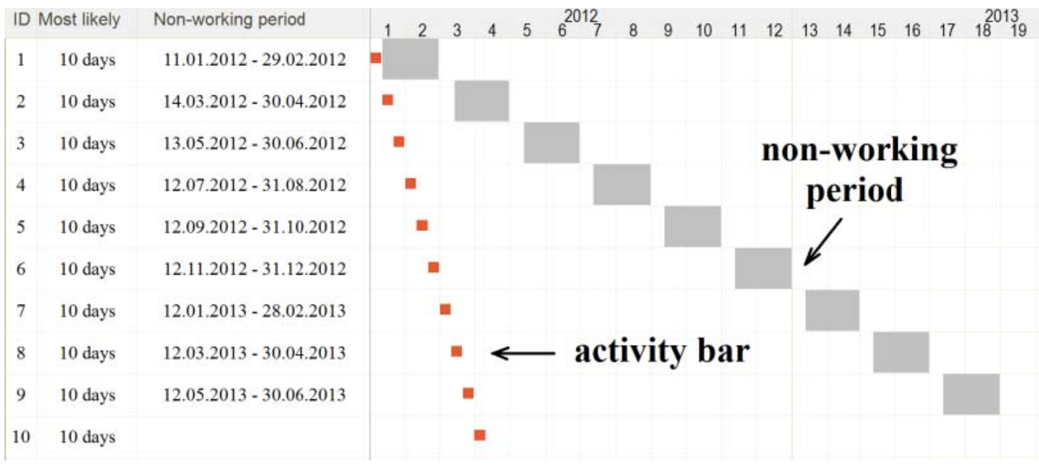

Figure 3. Sample PERT network (non-working periods depicted in gray) (see [20])

our different cases are created (Project #1 - #4) based on the same network and activity data but with different, only slightly modified calendars. These cases are summarized in Table 1.

Act. code	Work prohibited during the interval of			
	Proj. #1	Proj. #2	Proj. #3	Proj. #4
1	11.01 - 29.02.2012	05.01 - 29.02.2012	08.01 - 01.03.2012	06.01 - 01.03.2012
2	14.03 - 30.04.2012	08.03 - 30.04.2012	11.03 - 01.05.2012	12.03 - 01.05.2012
3	13.05 - 30.06.2012	10.05 - 30.06.2012	12.05 - 01.07.2012	13.05 - 01.07.2012
4	12.07 - 31.08.2012	12.07 - 31.08.2012	12.07 - 01.09.2012	14.07 - 01.09.2012
5	12.09 - 31.10.2012	12.09 - 31.10.2012	11.09 - 01.11.2012	15.09 - 01.11.2012
6	12.11 - 31.12.2012	13.11 - 31.12.2012	13.11 - 01.01.2013	15.11 - 01.01.2013
7	12.01 - 28.02.2013	13.01 - 28.02.2013	12.01 - 28.02.2013	14.01 - 01.03.2013
8	12.03 - 30.04.2013	14.03 - 30.04.2013	15.03 - 01.05.2013	15.03 - 01.05.2013
9	12.05 - 30.06.2013	15.05 - 30.06.2013	17.05 - 01.07.2013	17.05 - 01.07.2013
10	---------------	---------------	---------------	---------------
	Results in Figure 4	**Results in Figure 5**	**Results in Figure 6**	**Results in Figure 7**

Table 1: Same network, different calendars (see [20])

In the absence of analytic solutions, Monte Carlo simulation is used to create the distributions of the project durations in all cases. Results are shown in Figures 4 to 7.

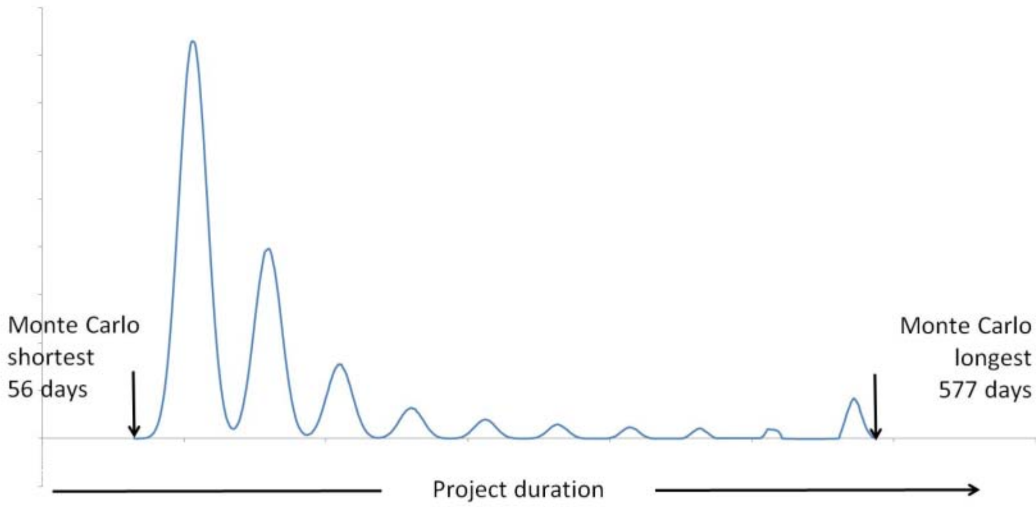

Figure 4: Distribution of the project duration (Project #1)

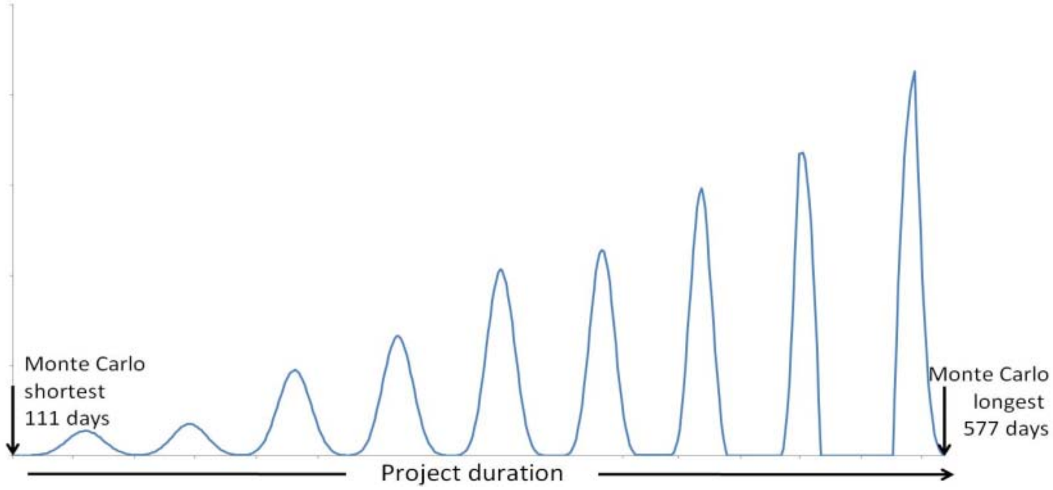

Figure 5: Distribution of the project duration (Project #2) (see [20])

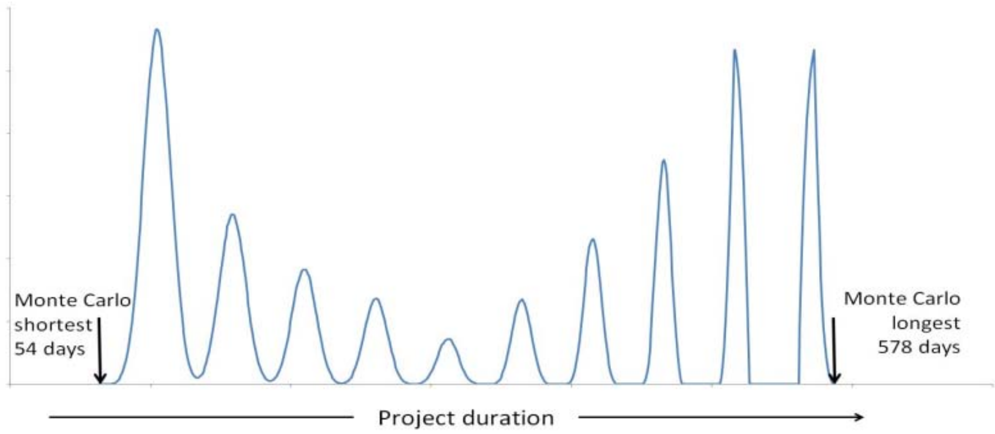

Figure 6: Distribution of the project duration (Project #3) (see [20])

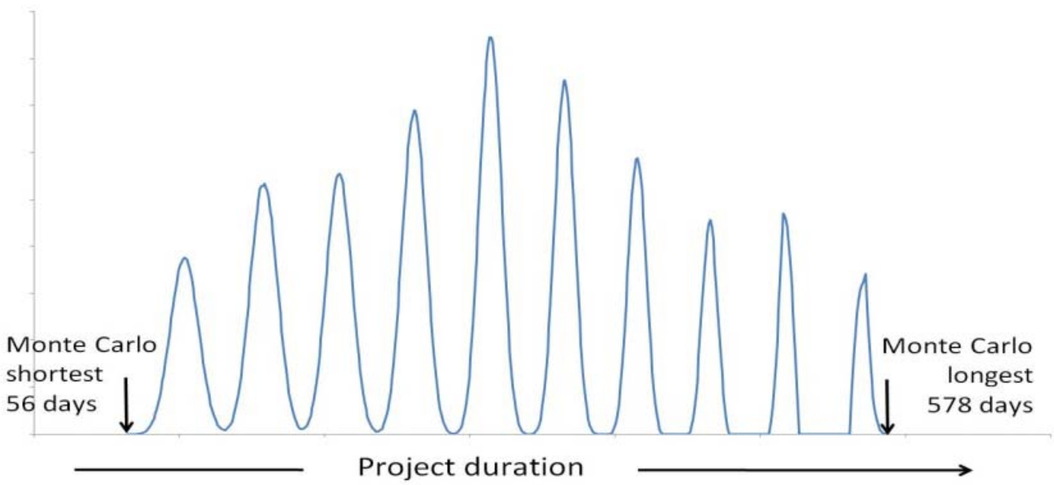

Figure 7: Distribution of the project duration (Project #4) (see [20])

In the following chapter, we show the effect of activity calendars on real life projects.

3. CASE STUDIES

3.1 Case study #1

Four real life projects are examined in the followings. All the projects have originally been planned using Precedence Diagramming Method (PDM). For the purposes of this paper all have been modified in the following way: PERT beta distributions have been assigned to each activity using the original duration as the most likely (m), 0.6*m as the optimistic and 1.5*m as the pessimistic durations.

The first network is a network of a highway construction project. It consists of 1015 activities including summaries, and 1112 precedence relations. The project duration of this precedence network is 601 working days. Four different calendars and time constraints for 160 activities – mainly for milestones – had been applied in the network. The "Start On…" and "Finish On…" constraints have been changed to "Start Later Than…", and "Finish Later Than…" constraints. The "Start Later Than…" and "Finish Later Than…" constraints have been left as they had been. The "Start Earlier Than…" and "Finish Earlier Than" constraints have been deleted. The constraint on the project finish has been deleted.

The probability distribution of the project can be seen in Figure 8. It is interesting to see that although the duration of the original PDM network is 601 days (30.06.2012), in this case even the shortest duration is longer. This is due to the "Start Later Than.." and "Finish Later Than…" time constraints. The expected duration is 730 working days. Due to the effects of the calendars and time constraints the distributions is far from what original PERT calculations predict.

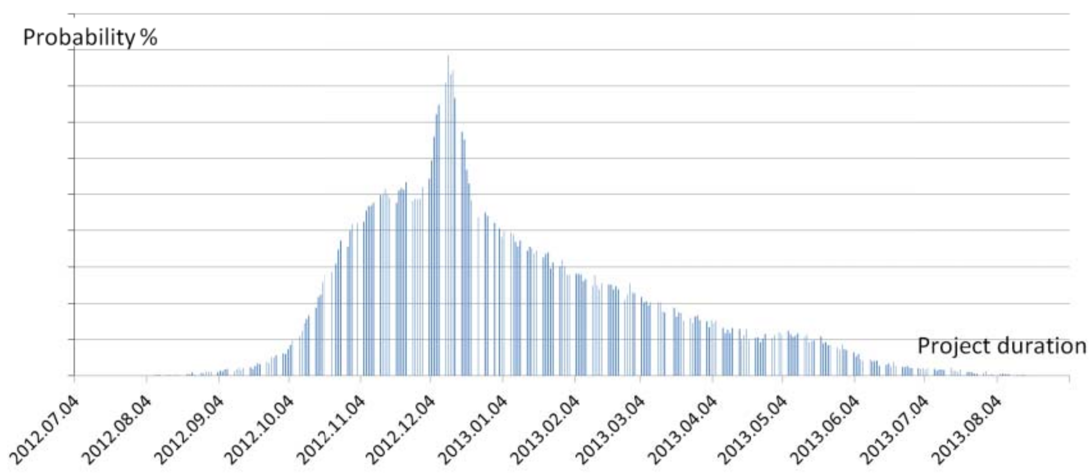

Figure 8: Probability density function (Case Study#1)

4.2 Case study #2

This network is a PDM model of a short section of a highway construction project. It consists of 364 activities including summaries, and 496 precedence relations. The project duration of this precedence network is 295 working days. Five different calendars and time constraints for 22 activities – mainly for milestones – had been applied in the network. They have been handled like in the case before. The probability distribution of the project can be seen in Figure 9. The gap in the middle is due to the application different activity calendars. The shortest finish date is 04.11.2010 almost the same as the finish date defined by PDM calculations, which is 295 days (10.11.2010). This situation has been caused by the different time constraints. Owing to the effects of the calendars and time constraints, the distribution is far from what original PERT calculations predict.

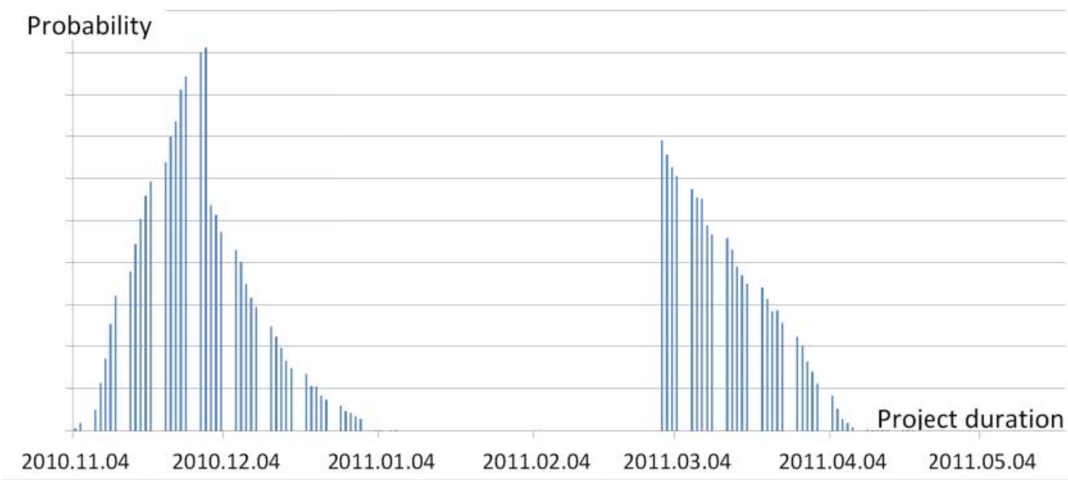

Figure 9: Probability density function (Case Study #2)

4.3 Case study #3

This network is a PDM model of another short section of a highway construction project. It consists of 437 activities including summaries, and 460 precedence relations. The project duration of this precedence network is 760 calendar days. Three different calendars and time constraints for 199 activities – mainly for milestones – had been applied in the network. The relatively large number of time constraints and relatively small number of precedence relations indicates that probably the planner had not devoted enough time to the proper definition of the project logic. Time constraints have been handled like in the cases before, although we have to mention that only "Start Later Than…" constraints had been used in the network.

The probability distribution of the project can be seen in Figure 10. The expected duration is 969 calendar days (25.01.2012), which is considerably longer than the 760 days (30.06.2011) of expected duration calculated according to the original PERT calculation rules. The shortest and the longest project durations of the simulations are 730 and 1140 days. The probability density function of the project duration again takes a new, unexpected form, and it is definitely far from the results, which can be obtained using the original PERT calculation rules.

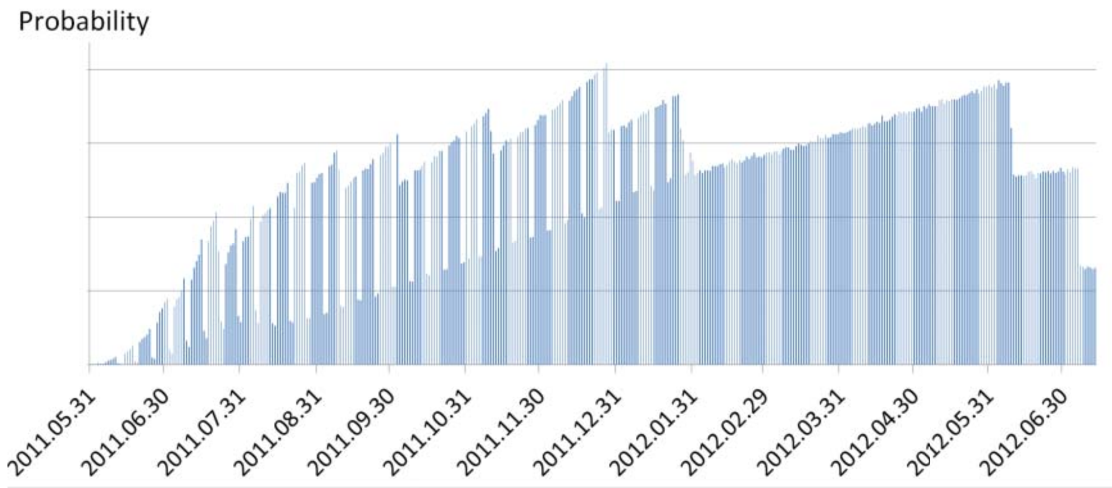

Figure 10: Probability density function (Case Study #3)

5. CONCLUSIONS AND SUGGESTIONS

This paper attempts to shed light on the fact that one key issue has not been considered in the course of PERT's multidirectional developments, namely, the effect of the application of different activity calendars on the project duration. It is obvious from the results that the effects of activity calendars on certain projects, which have been artificially specified for this study, are so significant that they cannot be ignored during analysis. The results show that disregarding activity calendars seems to be an oversimplification, which can distort the results of PERT networks to an extent even greater than the distortion caused by those simplifications for which PERT has received great criticism and which numerous researchers have tried to resolve.

Taking the effects of activity calendars into consideration opens up new directions for researchers working on PERT. The author believes that analytical results will not be available in the near future, and finding approximate solutions seems to be difficult as well. At the moment, calendars can only be handled by Monte Carlo simulations.

The sample projects used in this paper are artificial; therefore, in the case of real-life projects, the results must be validated.

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BUILDING REHABILITATION: THE GREENEST SOLUTION? CASE STUDY

Dr. István Hajnal
BUTE, Budapest, Hungary, hajnal.istvan@biggeorges-nv.hu

Abstract

Objectives of study: This paper examines the green performance of an award-winning property development, Bécsi Corner Office building. The developer potentially had two choices: to make a full rehabilitation or - after demolition - to erect a new building. The author investigates and compares the green performance index (LEED) of those two alternatives.

Methods: As all quantity surveying data are available, costs, technical specification details and also revenue stream are subjects of analysis. As the subject building was completed in 2009, the operational experience - including revenue generation potential - also was taken into account. The two alternatives are compared by incremental analysis, calculating economical benchmarks (Market Value). The study takes into account variables of green performance as materials, energy consumption, space utilization. Popular green rating systems (BREEM, LEED) also are investigated. The quantity of community contribution is determined by calculating the monument value.

Results: Public, economical and even sustainability aspects give good reasons of rehabilitation in case of the subject building. In case of a potential rehabilitation, only complex investigation gives appropriate result regarding green values. The case study also highlights the evaluation problem of green rating systems.

Keywords: sustainability, protected building, rehabilitation, market value, historical value, green ranking systems.

1. INTRODUCTION

Sustainability and green architecture have become indispensable accelerating power of the building industry being in crisis. This generated a new dimension in valuation of built environment. Nowadays it seems like that the latter valuation scale has become more and more monotone, even an exclusive trend. In my analysis, I wish to point out the different roles of the conventional real estate market indicators and the new, 'green' attribution. The subject of the study case is the development of Bécsi Corner in Budapest, a complete rehabilitation of a historical building through which the building has become a determinative establishment of the neighbourhood. The developer theoretically could have chosen the demolition of the existing building structures and erect a brand new building, but, based on a preliminary value survey, have decided to renovate the monument building complex. The experience of construction works and operation show that this was a good decision however, this is not confirmed by the general evaluation method of sustainability while other dimensions posteriorly certify the decision of the developers.

2. STANDARDS OF VALUE

2.1. The concept of value

The concept of value is applied on numerous situations or shapes in everyday life. Different value-qualifying quantities are used for qualifying built environment. These value-shapes visualize different things and quantify different dimensions. Beauty, as an abstract aesthetical category contains subjectivity, while it is difficult to measure it in the frame of social, societal or political dimensions. Even in professional real estate market we often find poorly defined value indicators such as usage value or technical value. Otherwise, the real estate professionals use numerous value-frames such as market value, liquidation value, security value and more. I chose three well-known and well-defined value markers to examine and to compare the different dimensions. These are i) the market value, being a generally accepted decision criteria for economic operators, ii) the monument value defined by Act LXIV of 2001 on the Protection of Cultural Heritage Article 7, point 7 and summarizes the decisive points of the Hungarian heritage protection into one value measure number and iii) finally among different sustainable classifications, the results defined by the LEED Certification.

2.2. The market value

The market value itself has more definitions. According to the year 2012 definition of governing body of the European Valuer's, TEGOVA, "the Market Value is that estimated amount for which the asset should exchange on the valuation date between a willing buyer and a willing seller in an arm's length transaction after proper marketing wherein the parties had each acted knowledgeably, prudently and without compulsion." There are severe methods widely applied by the real estate appraisers, while in respect of income-generating real estates, experts usually apply the method of capitalization of incomes.

2.3. The Monument Value

The quoted law intends to summarize different social points of view in one measure. This is why it created the category of monument value. The monument value of a historical building expresses the special alloyage of historical, artistical and moral values; expresses the significance that is attributed to the protected building by the society. The goodwill is not a market category. It is to express common interest, the common treasure of the historical building, as well as the appreciation of the society. The goodwill or liability value is determined by the positive correction of the reproduction value of the real estate. The applied coefficient (K) is determined between 1,0 and 3,0 on a relative value relation scale. The goodwill (E) of the monument real estate is determined by multiplying the estimated reproduction value costs (V) with the coefficient (K). (E = V x K). The factor (K) contains six variables among which the first two ones relate to the souvenir-factor, such as the antique value and the age of the real estate. The remaining factors replicate today's value judgement such as art, uniqueness, architecture and creditability.

2.4. Green Qualifications

In case of new constructions, the existence of green qualifications is indispensable at today's real estate market. There are several competitive qualification systems, while in Eastern-European practice, the most accepted ones are BREEAM and LEED rating systems. The certification can be obtained either in planning period or during utilization. The latter is definitely more difficult, therefore it is more valuable. The rating systems concentrate on buildings and take into account mainly energetic facilities. The appraised buildings gain scores and ranked into scales of qualifications such as platinum, gold, silver etc. Even though these complicated evaluations, requiring special competences, do qualify the urban, social or aesthetical relations, they are taken less into consideration at the final evaluations. The following table contains the spreading of the main score values of LEED system, illustrating that the social values do gain less.

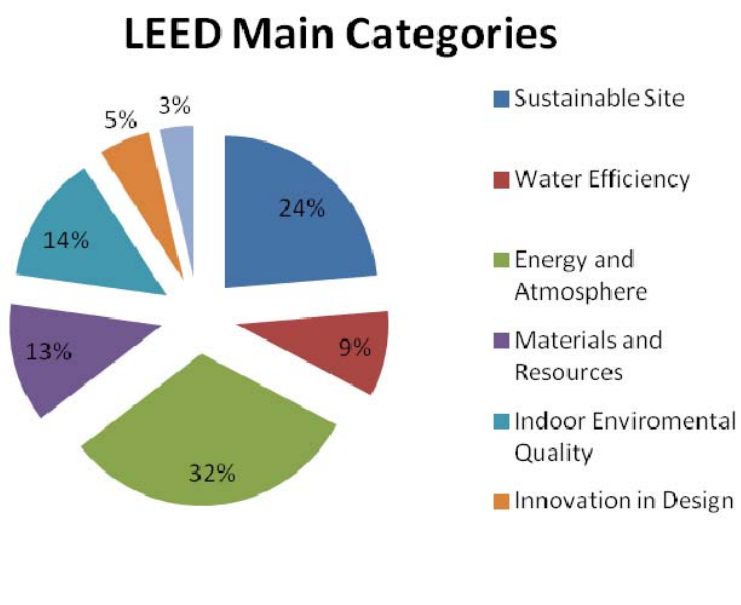

Figure 1: LEED Main Categories

3. CASE STUDY

3.1. Introduction of Bécsi Corner

The examined building complex is located in a traffic junction of Óbuda. The advantage of the location is that it can be reached by rail transport (HÉV – Suburban Railway) and it lays along the main road leading to the green belt area of Buda. In the neighbourhood there are more office buildings and commercial establishments, as the area is an important sub-centre of Óbuda. On the greater part of the plot there is a protected school building built in the middle of the 19th century, vacated and offered for sale by the local government. Next to the school building there is a baroque brewery built in 1728. Being the one and single storeyed bourgeois building in Middle-Europe, its monumental significance is invaluable. An empty plot was also part of the complex, ready for development. The real estate developer purchased the complex on an open tender from the local government, heavily considering on advantages and risks of the protected buildings. The construction works finished in August 2009 resulting a mainly office-complex with commercial units in the ground floor f.e. a bank branch, a shop and restaurants. GLA of the Bécsi Corner is 10.500 square metres. Presently, 95 per cent of the total rent area is occupied, which is an outstanding figure in the real estate crisis. Figure 2 shows an aerial view, while Figure 3 introduces the building through a photo montage.

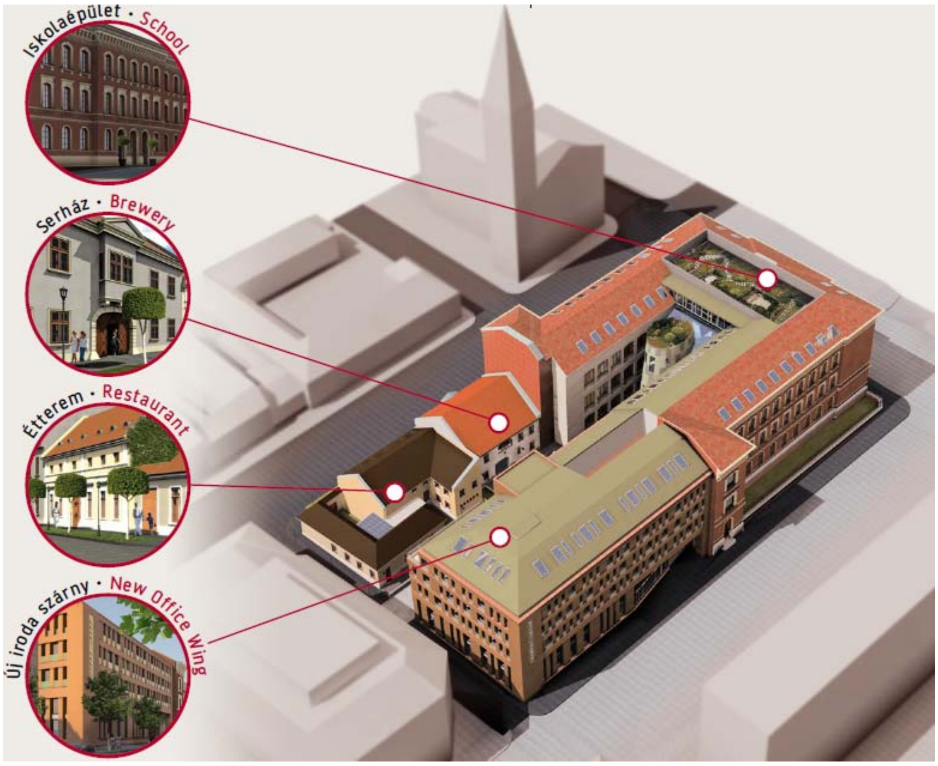

Figure 2: Areial view

Figure 3: Photo-montage

The building gained the "OSCAR" award of real estate development from the International Real Estate Federation, FIABCI Prix d'Excellence Awards in Heritage (Restoration / Conservation) Category in 2011.

3.2. Methodology

All expenses of construction works and facility management are known. The aim of the examination will be to model the three mentioned value measurers in the knowledge of the existing facts. The comparison is made between the completed building and an alternative to it. The second building, let us call it the Alternative Corner, would be constructed by the complete demolition of the monumental building and with a brand new, modern structure, according to actual office building standards[1].

According to the presumptions, the rentable area and the technical specifications of the two buildings, apart from the monumental potentialities, are the same. I did not take into consideration certain negligible factors in the interest of the comparability, while effects of other factors, for example time factor is simplified in the applied models. With regard to the fact that the management details are subject to trade secrets, the results can only be limitedly published.

[1] It is to be noted that no building permission could be obtained for the construction works of the Alternative Corner.

3.3. Examination Results

According to preliminary expectations, the maintenance fees to be paid by the tenants in the monumental building are approximately 7 per cent higher that is explained by the higher interior heights (vide Figure 4). However, the difference is significantly lower than the general expectations of professionals as certain experts presuppose the 20-30% of surcharges.

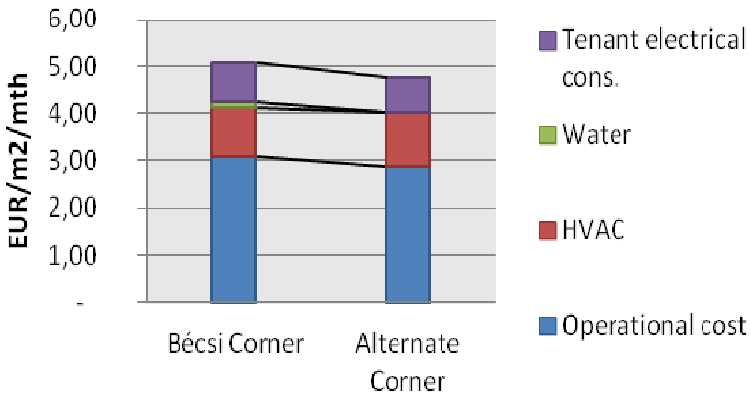

Figure 4: Comparison of operational costs

Similarly, the actual costs of the existing building are less different from the modern building than the expectations. The total costs of monumental reconstructions are 17% higher than the full costs of construction of a new building. Reconstruction costs were reduced by keeping certain structures, however, the increasement was mainly caused by the planned and unexpected costs of monumental preservation works. The following illustration, Figure 5 indicates the comparison of development budget by main types of works of Bécsi Corner and the Alternative Corner.

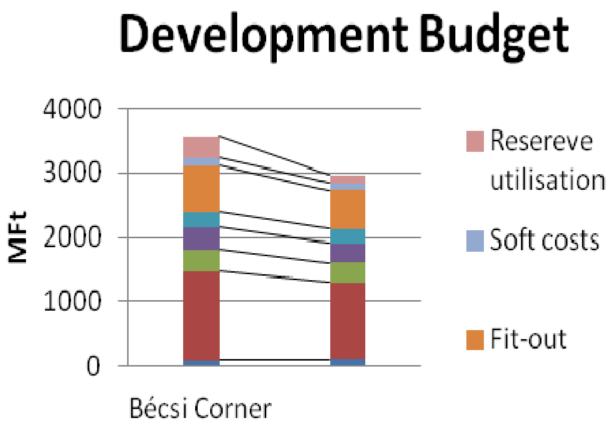

Figure 5: Alternate development budgets

There is a turnover in the revenue side in favour of Bécsi Corner. Taking into consideration the market circumstances, the achievable tenant fees are slightly higher in case of the monumental building, but the market shrinking significantly derails the results. The general shrinking of the neighbourhood is 25%, while in case of the examined building in reality, it is only 5%. Figure 6 projects the above on the full income-generating potential.

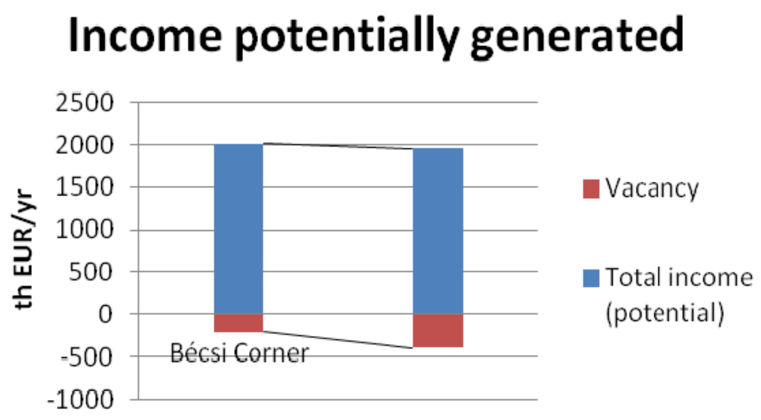

Figure 6: Income potentials

From he above variables, with the residual valuation approach, the market value of the real estate was derived by the yield calculation valuation method. As it could be expected, based on the earlier decision of the real estate developer, as well as the presently analyzed results, the market value of the Bécsi Corner is significantly, almost 20% higher than the alternative utilization.

According to the methods and relating valuation rules described in point 2.3, I defined the Monumental Value of the building complex. The similar calculation can be prepared in respect of the alternative building as well that indicates that the monumental value calculated by the described method is smaller than the Market Value. The difference in this dimension is 40% for the benefit of Bécsi Corner.

In respect of the third index, the examinations ended by astounding results. In vain of the indisputable advantages of Bécsi Corner on the society, the environment and the city view, in vain of value protection and introduction, in the “green dimension”, the new building received higher results. As a result of the monumental rehabilitation, in LEED rating system, the Bécsi Corner received only 4 extra points out of 110, while in lack of the modern building structures and unsolvable energetics solutions, the results were 16% behind the alternative building. The following diagram on Figure 7 indicates the comparison according to the three measures of value.

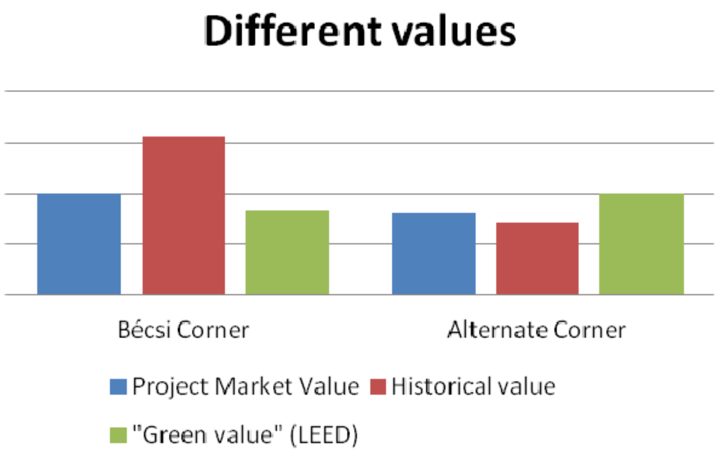

Figure 7: Different values, different dimensions

4. CONCLUSIONS

In the possession of the concrete experiences, the case study certifies the well-known fact that the more expensive, monumental implementation can be compensated by the higher utilization and the higher rent fees, by which, a higher market value can be achieved. The real estate development decisions are made based on the market value, that are properly direct the investors towards protecting the community values. In this case, it was also well visible that among costs factors, the application of unplannable reserves gives the highest uncertainty. At the same time, the “green” valuation dimension does not contain the points of view of “commonweal”, especially heritage protection. Because of this, the nowadays fashionable sustainable qualifications do not rank the reconstruction of monumental buildings by important points of view of the community.

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Act LXIV of 2001 on the Protection of Cultural Heritage

LEED: *http://www.usgbc.org/leed*

BREEAM: *http://www.breeam.org/*

FIABCI: *http://www.fiabciprix.com/winners-2011/heritage-category/becsi-corner.html*

ARCHITECT EDUCATION IN THE LIGHT OF THE REAL ESTATE CRISIS

Dr. István Hajnal, FRICS
Budapest University of Technology and Economics – Department of Construction Technology and Management Budapest, Hungary, hajnal.istvan@biggeorges-nv.hu

Zoltán Rostás MBA, master lecturer
Budapest University of Technology and Economics – Department of Construction Technology and Management, Budapest, Hungary, zrostas@gmail.com

Abstract

The crisis in real estate industry and the expected renewal of the market afterwards provides the extension of traditional architect engineering education. As surveying the life cycle of real estate industry, the Authors suggest to reconsider the professional education of architects. While architect education curriculum dates back several decades, even hundreds of years, education of real estate profession knowledge has a short history, it can lean on little antecedents. To apply the knowledge in higher education, to enable institutes to apply similar standards in respect of competences, it is necessary to create an adjustable database of knowledge. Architects have to play important role in the management of the real estate or a group of real estates, in optimalising utilisation of a real estate, the adaptation of principles of sustainable building, as well as any other innovative activity that would target the effective utilisation and development of building or real estates, or groups of real estates. Regarding this, Authors do suggest the introduction of a special workshop and form of education that brings the knowledge of real estate profession on an academic level. They hereby wish to make suggestions on main elements of a planned MSc education of real estate profession, based on international samples and their own personal educational experiences.

Keywords: Education, Architecture, Real Estate, MSc, Crisis.

1. INTRODUCTION

The Effects of Global Real Estate Crisis on the Community of Architects and Architect Education

The global real estate crisis lasting for three years now has been redrawn real estate market. High profit disappeared, the period of overcredited speculative developments finished, while sustainability has been highlighted, including maintenance, reparation works, area rehabilitation and green solutions at new projects. Building volume is decreasing, community investments are spreading, parallelly, the social control of developments is increasing. In this very different environment, the role of different contributors as well as architects is changing. In the interest of finding the way to success by newly graduated architects, moreover to assist elder colleagues to move out of the condition of practice of decades, in our opinion necessary steps have to be made within education as well. Actors of the market have their serious claims to employ manpower suitable to the 'new world', while architect students are continuously looking for areas where they are able to start and build their professional careers.

We wish to discuss matters of the education of architecture engineering (and not any other engineering or economic profession related to building), because the profession of architects is one of the few that is mutually accepted by all member countries of the European Union[1]. It is an acknowledgement to their universal knowledge and the practice of their profession along similar values all over the EU, such as doctors, pharmacists and dentists. This means an education based on similar requirements – of which possible changes are examined by us.

The crisis has changed the professional career perspectives of our students, who expect not only scientific and professional knowledge but exemplification from their lecturers. This is why they come to us and request for advice more often: where to turn to, what to study to gain an employment as architects. We are looking for possible answers to these questions as well by writing this article.

In the first part of the article, we analyse the problem (A – audit), we make a survey on the related literature and education (B – benchmark), make a conceptional suggestion (C – conception), and analyze the possibilities of solutions within the frame of the education of architect engineering (D – development) – following the ABCD problem-solving model (Rostás, 2007).

2. AUDIT – SITUATION ANALYSIS

The consequences of crisis are shown in the main indices of real estate economy. The rate of home building (planning[2]) decreased in Hungary by 21.2% from the value of the year 2003 by 2011 and dropped by 11% in 2010[3]. The tendencies of European building industry show less decrease: compared to the peak in 2006, the volume of production decreased by 78.9%[4] in

[1] DIRECTIVE 2005/36/CE DU PARLEMENT EUROPÉEN ET DU CONSEIL (7 septembre 2005)

[2] We investigate the change of number of issued building permits on home planning, because according to surveys (BME 2004, Rostás and partners), more than 55% of the architect engineering activity is constituted by planning apartments.

[3] Source: KSH Statistics of Apartments 2012

[4] Source: EUSTAT, Production Index in the Construction Sector 2011

2010. The buildings that are not to be constructed, do not have to be designed either, therefore the relapse is also significant at the planning service market.

Significant part of the Hungarian architect studios is seeking for orders. Most of them live on their savings, others close down. According to analysis (Rigó, 2011), not only the lack of work, but the conditions of contracts, low prices and also the lack of payment discipline altogether drive the design and engineering studios into bankruptcy. The graduated architects are not in the position to find either jobs or 'masters' who could teach them the knacks of their profession. According to French surveys (IFOP, 2011), the newly employed young architects after graduating from the university, are not able to carry out independent projects for 9.6 (11.4)[5] months.

The aim of professional chambers to be at their members' assistance, therefore they seek the way of participating in legislation, by establishing the criteria of professional registration and launching professional education trainings, organising exams[6].

However the latter concerns only partly the group of students as well as the renewal of the university education relevant in our examination. Bálint in his detailed article (Bálint, 2011) characterises the old fashioned style of Hungarian architect education. According to his evaluation, the education does not prepare the students to the everyday process of building industry, while there is an introduction and calling on account of an idealized world in higher education. The general negative statements of Bálint could be presented through severe examples Authors experienced during their daily education routine. Most of the time, planning exercises are marked by non-realistic functions, non-existing plots, disregarding of planning regulations, neglecting thrift and economical feasibility (target cost planning) and evasion of simulation of the real (building and architectural) market environment. More and more students are unsatisfied and vindicate establishing and practicing real planning exercises. The above might be an important direction of development.

Bálint refers to the fact that presently there is a conversation on renewal of Hungarian regulation between the Ministry of Interior as regulator authority, and professional chambers as well as higher education institutes in the frame of the National Architect Forum (OÉF). According to the plans of the regulatory authority, the different forms of education are to be built on a unified credit-based system, making it possible considering not only competences but also entitlements. However, in respect of qualifications and entitlements, the involved organisations are still attached to old schemas. Hajnal in his lecture (Hajnal, 2011) urges integrity of education of real estate profession to different levels of education in the interest of satisfying market demand.

[5] The basic data considers full time employees. Coaching time of part time employees or project employees is indicated in brackets.

[6] The Hungarian Chamber of Architects organises exams for fulfilling management exercises, for example, and at the same time, proactively cooperates in the work of National Architect Forum.

Certain components of the education suggested by the Authors are already part of the education material of Department of Construction Management and Technology both in respect of mandatory subjects (Rostás, 2006) as well as facultative subjects (Hajnal 2000), (Hajnal 2007). However, even in small number of hours, the topics of investment planning, real estate development, basic knowledge of real estate management are already represented in these subjects of traditional architecture education.

Renewal of the education is targeted by the continuous representation of BME Faculty of Architecture in OÉF as well as activity in the work of the Building Economical Strategy Committee (Becker – Rostás 2011), furthermore, the development programme[7] financed by the EU, as well as organisation of sample programmes such as ODOO Project[8].

3. BENCHMARKING – SAMPLES, EXAMPLES, PRACTICES

With regard to the fact that the Hungarian architect education and practical work of architects had not been focused by scientific examinations for a while now (Szilágyi, 1981), (Rostás and partners, 2002), we have to work with Anglo-Saxon and French data.

In the frame of Anglo-Saxon education, the real estate professional trainings have had traditions for a long time. The renewal of programmes at all educational institutions are under process since the crisis (Porter, 2011). The real estate professional trainings are parallel attached to the training of architects, therefore the renewing contents have direct effects on the education. In an earlier analysis prepared for the Hungarian branch of RICS, Hajnal surveyed the topics and the offered credits of different educational levels (Hajnal, 2007). According to the experienced, an integrated basic requirement has been developed formed by the technical – economical – legislative knowledge, supported by more or less practical knowledge. It is not surprising on global real estate market that the method of education is also global, more than that, it is inevitable on economical field. Although construction law is different in all the countries, and EU does not enforce unification, the products of building industry, as well as related methods, agreements - according to the conditions of financing beyond borders – do show a coherent picture.

The beginning of the crisis of architects reached France a little bit earlier. Even in the period of the building boom, the design exercises started to decrease and finding a job had become difficult for young graduated experts. At the same time, the Bologna reform reached its peak that turned the traditional education upside down. Reformation of education of architects[9]

[7] HEFOP – Human Resources Development Operational Programme – for the development of the five research focused area of the university.

[8] http://www.odooproject.com/en/

[9] In France, there is education of architects only, not engineers.

extended[10] with a new element. It had become possible for young architects to practice their profession alone, they were not obliged to get employed on the overloaded[11] market. It can be stated that the employment of the graduated – that was, in the beginning of the 2000s practically 100% in Hungary – deteriorated more here than in France. The Bologna principles had been applied in the (engineering) architect education in both countries, meaning that in this field, Hungary had no arrears. The possible reasons can be however, that Hungary suffered from a deeper crisis of building industry, the lack of sources were higher – and the planning exercises were much more less. However, one similarity is to be mentioned: in both countries, unemployment rate among architect services were equally higher around the capitals and their agglomerations.

The question is, whether the crisis was a blessing or a course? Is there any possibility for renewal? The reply of France was yes to the above question. The so-called Grenelle Committee (Le comité stratégique du Plan Bâtiment du Grenelle) that made suggestions within the frame of a programme launched in 2007, highlighted the further training of architects in the field of environmental quality ((Haute Qualité Environnementale – HQE) and sustainable development.

Sustainability and the green idea is probably the first element that could find its way and break through the old-fashioned, decade-old architect- and engineering education. It is natural that by spreading of the industrial application, it gained more space but teaching it is still problematic (Itard et al 2011). Clients' needs are sometimes ahead than the technology in practice. The requirements of different building quality control systems (BREAM, LEEDS) would have requested for immature system applications. It is not accidental therefore that only the principles are discussed during the education – as such principles are discussed in Lányi's study (Lányi, 2010) – while utilisations of different building systems can be studied only in building exhibitions or at their developers.

The points of reference (benchmarks) of renewal of education are i) EU-organisations, ii) international organisations of building industry, iii) other educational institutions, and iv) standpoint and opinion of experts. A survey prepared on the request of EU (DTI, 2009) provides four screenplays[12] for the building / real estate industry subsystem by 2020 considering the market and the regulations. It names three important skills, which are regarded as being of increasing importance: a) Planning and management skills b) Sustainable construction processes c) Adoption of new technologies. In respect of higher education, with regard to differences of education systems among countries, it makes different exercises for institutions. First and foremost, it recommends the enforcement of

[10] Arreté du 10 avril 2007 relatif a l'habilitation de l'architecte diplômé d'Etat a l'exercice de la maîtrise d'oeuvre en son nom propre – Minist`ere de la Culture et de la Communication; Order on securing the right for obtaining skills for providing individual work – Ministry of Culture and Communications

[11] In 2008, 91% of architect studios omitted to employ any entrants. (source: Observatoire de la profession d'architecte 2011)

[12] 1. Hire and fire, 2. The independent specialists, 3. High Tech playground, 4. The Village

relation between market actors and the education, as well as the forcing of continuing education and training (CET).

Article 46 of the relevant EU order (Directive 2005/36/CE) indicates necessary principles for mutual acceptance of architect degrees. In respect of the knowledge of building architects, point g) emphasizes project management, point j) the cost and regulations restraints, while point k) mentions the importance of (building) industry, its organisations, rules and regulations, processes and (project) planning.

The International Union of Architects (UIA) might be the most competent[13] body in the definition of the necessary knowledge basis that was laid down in 1993 and was renewed in July 2005. Among these we wish to emphasize[14] the following, in relation to our study:

- Awareness of responsibilities toward human, social, cultural, urban, architectural, and environmental values, as well as architectural heritage.
- Adequate knowledge of the means of achieving ecologically sustainable design and environmental conservation and rehabilitation.
- Development of a creative competence in building techniques, founded on a comprehensive understanding of the disciplines and construction methods related to architecture.
- Adequate knowledge of project financing, project management, cost control and methods of project delivery.
- Training in research techniques as an inherent part of architectural learning, for both students and teachers.

The most important among the samples is that what kind of further education trainings do the architects attend, what further (new) skills are important for them to obtain. In a previous survey (Rostás et al, 2002), the students graduated within five years, intended to attend to further trainings in the fields of (as a matter of importance) i) financial – economic – legal sciences, ii) building construction planning, iii) building technology studies, iv) urban planning.

According to actual French data (IFOP 2011), the most popular subjects are: i) sustainable construction (59%), ii) IT (22%), iii) accessibility and universal design (22%), iv) building materials, legal knowledge and building diagnostics (12-12%). It can be clearly seen that during the crisis, the knowledge related to practical realization is overshadowed (management (10°), provide against natural disasters (8%), workmanship knowledge (7%)). However, it is interesting how the respondents talk about utility of above knowledge and professional importance. The order is different from above. The most practicable skills are: i) IT, CAD (93%), ii) legal knowledge, (91%), iii) accessibility (91%), iv) communication and management (90%) – the utility of sustainable construction knowledge has not been mentioned in the beginning of the list.

[13] The above EU-directive mentions certain parts from the material of UIA

[14] Highlight from Authors

4. CONCEPTION – PRINCIPLES OF RENEWAL

Authors are practicing lecturers of the BME Faculty of Architecture, and at the same time, participants of the industry, therefore they can see architect education both form the inside and as market participants from the outside at the same time. The general negative statements made in the introduction can be illustrated by life-like samples. One of the biggest imperfections is the lack of knowledge in the field of market process. Architect students are not able to position their activities and exercises within the network connections of different cooperating partners (developers, contractors, authorities, financiers, civilians), they do not know the different drifts, aims and patterns. This is how the efficiency and return are only secondary points of view for them. They are not aware of the fact that there is an economically optimal way of building among different construction alternatives the one that provides the highest profit for the owner. This is why the owner and the financier are to demand this economically optimal solution from the architect. It is highly important within this sphere – especially at community investments – the optimalisation of the complete life cycle cost, to which it is necessary to discover even during the planning, the possible methods of effective operation, it is essential to plan the maintenance and its organisation. Students do not know the needs of operation, possible tools, and the forms of organisation, moreover, they are not aware of the order of size of related costs.

The regulations of building are continuously changing, therefore it cannot be a requirement for students to study all concrete authority regulations. While most part of the daily work is filled by contacting the relevant authorities and fulfilling the adequacy, architect education do not prepare students for such activities neither theoretically nor practically. Similarly to this, the everyday activity of contractors and relating processes are not appearing in the closed educational universe of universities.

Brokers, advisors, appraisals and other co-operators assist the circulation of the real estate market. Significant part of their job is the technical analysis, due diligence and recording. Architect students do not know these specialties, moreover, they do not have any idea by what job they could assist to the daily exercises of the co-operators – this is how a market segment remains closed in front of them. It is very sad, because professionalism is sometimes missing from the work in inland practice – since it is not completed by well-educated professionals.

We do see the possibility of renewal in the field of architect training by trying to put together our professional experience and principals in the following areas.

4.1 Necessary Real Estate Workshop

We believe we could back that real estate market is essential to show up as determining professional environment in architect education. While architect education curriculum dates back several decades, even hundreds of years, education of real estate profession knowledge has a short history, it can lean on little antecedents. To apply the knowledge in higher education, to enable institutes to apply similar standards in respect of competences, it is necessary to create an adjustable database of knowledge. Professional knowledge is to deepen with basic research and organisation of knowledge at an academic level. While such academic basic is already available for students at earlier mentioned foreign institutions, in Hungary, it is still to be achieved with the establishment of a suitable workshop being embedded in market and academic environment. At the BME Faculty of Architecture, Department of Construction Technology and Management, the real estate education has a decade history now that establishes a good basis for the settlement of a real estate professional workshop. The significance of such knowledge centre is that its education material would be used in other institutions and other educational levels; the graduated students might become researchers, PhD students and potential lecturers, experts of certain topics; and at last but not least, the given and gained knowledge makes standards to obtain certain entitlements.

Hungary was the first country in the Eastern Block that firstly joined the group of countries having modern experience in real estate market, and therefore could take part in activities of international organisations like RICS, TEGOVA or FIABCI. The obtained experience became part of the real estate culture in the past twenty years, however, appeared partly only in education. The seriously different syllabus of licence-providing trainings became unified by today, but could not be integrated into higher education and mainly architect training either. The mentioned materials of courses grew up in different professional organisations' workshops, later the lecturers trained each other until the time today's requirements and material developed. This procedure is analyzed in an earlier phrase by one author of present article (Hajnal, 1996). Such a workshop had been established in the Budapest University of Technology and Economics, Institute of Continuing Engineering Education. The materials discussed here became lecture notes which laid down the expected knowledge and requirements. This workshop received the inquiry later to take part in the creation of the Hungarian real estate valuation legislation[15] and concluded the final codification and standardization of the educating material.

5. DEVELOPMENT – STEPS OF IMPLEMENTATION

5.1 Creation of Education Syllabus

The adequacy with the new market environment can be best assisted with launching of new programmes. Partly with this aim, we are preparing a new accreditation of real estate MSc level education. We have summarized all knowledge that graduating architects, according to our professional experience and research works, have to carry along themselves into practice. Those who intend to function in the real estate market, real estate profession, have to interiorize the whole of the package, while those architects, who intend to be employed in the field of urban planning, architecture design or even in public sector, are suggested to learn an extract of this knowledge.

[15] 25/1997 (VIII.1.) order, Ministry of Finance

The real estate MSc presents the widest circular – spiral model – based on the knowledge related to the life cycle of the real estate. Knowing of the market and common interests, the different competitors, the surveying of utility alternatives, the construction of the building programme, the choosing procedure of cooperating partners, conduction of the project, assuring the necessary financing, and at not least, maintenance and finally recycling create the arch lengths for decades that the students have to understand and handle in a unified approach. In this procedure, the architect has a determining role as his knowledge makes him an essential part of the process. At the same time the co-professions are also significant, the real estate branch also requires basic economical, legal knowledge, market orientation, and analytical, sales, management and communication skills. The international and Hungarian actors of market define clear expectations towards the knowledge; such knowledge is educated in the frames of graduate and postgraduate trainings at universities of countries with developed real estate culture. (Porter & Duglas, 2011). Presently, such training is existing only in postgraduate form in Hungary, however, based on experiences, the syllabus of the inland educations can be also applied.

The suggested MSc education has to be introduced with the necessary credit value and time distance in the interest of the learning of spreading knowledge and the relating practice. We suggest 120 credit demands to obtain within the 4-semester qualification. The acquirement of knowledge is to become in full-time education system. The enrolling students need to have legal, economic or technical (civil engineering, architecture, building engineering) basic qualifications.

The material contains obligate and facultative elements. The spine of basic knowledge of the real estate profession is formed by the technical, legal and economical subjects. At the technical field, the two-semester basic subject of building structures and systems, as well as its’ failures is determining. Real estate law includes the relevant knowledge of civil law (ownership, contractual law, lawsuit management), the presentation of land registry system, legal regulation of building and the legal background of the authority procedure. The third basic subject, the real estate economical studies makes the students familiar with the engineering-economical calculations, practical statistical applications and portfolio calculations. The engineering line is supplemented with project management, urban architecture and building energetics. The economical line is supplemented with real estate financing and real estate appraisal. Further basic real estate profession subject are laid down to these fundaments such as real estate development and facility management, as being practice-oriented subject of the two main wings followed by real estate experts. Within this frame, the real estate agency and real estate marketing are also introduced to students. The facultative subject offer specialization covering wide range of leadership knowledge, detailed knowledge of real estate practice as well as courses relating to the sustainable environment.

Participants of the real estate market have an opinion that the knowledge provided by the real estate development MSc would open further possibilities for graduated architect, law or economy students with a basic education. The earlier detailed changing real estate market is in a lack of young professionals representing new approach, having excellent problem-solving skills and complex point of view. Either public real estate developments, building maintenance or facility management require the rising generation of experts, the assistance of managers in higher positions. At the same time, the now enrolled students, hopefully, will arrive to an already stabilized market that offers development exercises again.

5.2 Launch of Education

Introduction of new courses and training programmes is a long project in Hungary too, therefore the education of real estate market knowledge can be practically developed in the ground of already existing training forms. It requires that the regulated frames of hours of accredited education courses are grouped by guarding the principals already accepted during the course of accreditation. Only the knowledge has to be up-to-date. Namely, along with the invariable educational structure, it is necessary to provide place for the above subjects by grouping of hours. This causes decrease of hours of certain courses of the basic architect education, along with conflicts of interests. The querying of subjects of traditional education is already an heretic idea – even if the lecturers have to provide certain amount of their hours for a new, unknown and suspiciously ’market oriented[16]’ group of subjects. Cons are known in advance: making games of the hundred-year old traditions, the heartless serving of the market, the loose of general character of education because of filing in some ’fashionable’ subjects etc.

This is why we decided to launch the real estate market knowledge from the further training system to the full time (basic) education by starting MSc course as an addition to the architect basic training balancing among traditional, engineering and artistic education.

CONCLUSION

Our lecture practice and professional experiences made us to go over what the after-crisis world requires from architects. Our surveys, personal experience abroad, as well as consultations with professional organisations, employees and building experts showed us that one possible way of the renewal of the architect education might be the wider, scientific and practical introduction of real estate market knowledge. Architects of the future are to role in every phrase of the life cycle of the real estate – not only in architectural planning that is the basic aim and heaviest element of today’s education. They will have to be there where regional and urban development conceptions will be worked out. They will have to be there at development project management, at the establishment of programmes of certain buildings, at the preparations of feasibility studies, at directing the planning procedure on the builders’ side, at solving special constructional and energetic planning exercises as well as at the construction, material production, development and adaptation of special technologies.

[16] Following almost forty years of socialist management, in the middle of the economical crisis generated by illness of the newly establishing capitalism and the collapse of the real estate market, many do think that the ’market attitude’ is still against scientific thinking and ethic behaviour.

They have to play important role in the management of the real estate or a group of real estates, in optimalising utilisation of a real estate, the adaptation of principles of sustainable building, as well as any other innovative activity that would target the effective utilisation and development of building or real estates, or groups of real estates.

The launch of an education in the frame of an MSc course, based on the above principles – according to foreign samples – is an imperative need in Hungary as well. This article is to serve this aim by enlisting scientific and professional arguments.

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THE IMPORTANCE OF DESIGNING ACCESSIBLE ENVIRONMENTS WITHIN HOTELS IN THE UK – INVESTIGATION TO SEE WHETHER NEW INNOVATIVE HOTEL DESIGNS COMPROMISE ACCESSIBILTY

Paul Hampton BSc (Hons) MSc MRICS FICWCI FHEA PGCert ED
University of Wolverhampton, Wolverhampton, WV11LY,

Abstract

Accessible Environments are a vital consideration in any design of hotels. With the focus of attention moving more towards iconic designs and carbon climate change initiatives, is the design focus moving attention away from making sure accessible environments are including within the Designers/Architects brief. This research will review and investigate a possible exclusion of accessible environments as a key design consideration for hotels based within the United Kingdom.

When the 2004 version of the Approved document M entitled “Access to and Use of Buildings” was introduced it replaced the 1999 edition of “Access and facilities for Disabled” and looked to remove the stigma that was associated with creating more accessible environments. The document was trying to remove the idea that creating accessible environments restricted design innovation, and looked to move designers towards accepting accessible environment design as the norm. The new document looked to give clearer guidance to the designer/Architect and supported by associated documents British Standards BS8300 and good design guidance, provide pictorial and illustrative evidence of what was seen as good practice.

Directed initially at designers/Architects, contractors and Building Control surveyors the new document introduced new changes to draw a closer association with the Disability Discrimination Act 2005, and recommendations surrounding BS8300 “Design of Buildings and their approaches to meet the needs of Disabled people” since amended to include updated revisions. The intention was to guide the designer/Architect through a journey from approach to the building or facility and then provide guidance surrounding the environment individuals would encounter as they moved throughout the building and used specific facilities.

One of the main buildings which require further guidance on creating safe accessible environments is hotels. Hotels are generally privately owned, part of a large hotel chain and can be located in prominent land locked locations like city centres. The other specific risk associated with hotels relates to fire safety. Visitors will be unfamiliar with their surroundings, and some of its occupants will require assistance to evacuate the building, and good design should incorporate safe measures to facilitate all these challenges. The guidance recognises certain design restrictions apply and constantly make reference to what is viewed as “Reasonably

practicable". This has since been tested in court, and the test of what is "reasonably practicable" takes in to account the size of the organisation, the financial power of the organisation, and the level of engagement and regard given towards trying to promote best practice and create accessible environments. Whilst the Approved document M is only one way of meeting the requirements, it perhaps guides the designer to recognise what may be viewed as a minimum recommendation or standard. Modern hotel designers/Architects are looking to create iconic buildings with new innovative environments; but at what cost to accessible environments. In trying to meet the clients brief for bold statements of design, accessibility may be compromised.

The research will incorporate the findings of a Quantative data collection undertaken with Designers and Architects based within London and the West Midlands who work with Hotel clients and seek to evaluate whether practitioners are still considering the relevance of incorporating accessible environments in to their design brief for hotels located in the UK.

Keywords: Accessible Environments, Hotel design, Approved document M.

1. INTRODUCTION

With the global economic downturn, 2011 – 13 the United Kingdom increased footfall and occupation numbers of UK hotels and a decline in of overseas travel my UK citizens. This placed greater demand for hotel accommodation in the UK, and a greater demand from Architects and designers to better utilise the use of space. Added to this was the increased demand for hotel accommodation in London and surrounding cities as the Olympic Games came to London in the summer of 2012. UK investors and hotel chains had foreseen this increased demand, and during 2011-13 this increase for hotel accommodation rose by over 5%. In 2013 more hotels are awaiting planning approval, and many more are nearing a feasibility stage. Organisations like Hilton, Premier Inn, holiday inn and Marriot have either looked to increase their real estate asset numbers across Great Britain or are looking to refurbish existing stock to keep track with market demand. With the drive to find new economic ways of reducing energy usage, designers have been required to ensure new designs provide sustainable buildings. One example of this will see increased use of space consuming electrical and mechanical plant, and ways of adopting more energy efficient passive infra-red (PIR) lighting. However both design applications must not compromise space dedicated for the creation of accessible movement around buildings, or as quoted in BS8300, removing the need for adequate lighting levels to be available throughout the building, paying particular attention to hotel reception areas, stairs, corridors, and locations where instructions or reading may take place. Whilst remembering that the main focus of the guidance states in M1 – "Reasonable provision shall be made for people to: gain access to and use the building and its facilities" Approved document M (2013:pp8).

The ease of identification of entrance facilities is crucial for visitors to the hotel, but with greater use of externally glazed facades, and solar glazing with high reflective surfaces, the challenge of compromising identification of main entrances may be difficult. Designers should where possible avoid glare from shiny surfaces, and ensure that manifestation is clearly identified. To aid visitors to the hotel locate the entrance careful use of contrasting surfaces should be incorporated into the design, and the use of solar powered technology may help in providing more accessible entrance doors (semi-automatic entrance door operating push-pads).The use of brighter more distinguishable colour schemes, and more distinctive signage, can further aid the identification of entrance routes, this can assist visitors to locate suitable parking facilities close to the entrances.

Another consideration is the use of external lifts. If designers are more careful with their setting out of entrances, the use of ramps can be minimised, and any changes in levels can be incorporated within the main entrance into hotels. Historically changes in levels have seen accessible entrances move to the side and/or rear of the hotel. However new iconic design that are looking to create streamline facades, may need to adapt their designs to create innovative solutions.

Use of reduced Lux lighting levels is also a major consideration. For some user groups, and particularly with an ageing population, increased lighting levels can be imperative for increase vision, and mobility around the building. It is imperative that designers embrace new LED lighting technology to enhance their lighting levels and prevent poor mobility. Of the four new hotel designs viewed, and the six hotels visited all had looked to use natural light (which is commendable) or had conversely looked to decrease lighting levels. This practice of trying to create an atmosphere (mood lighting) must be carefully considered.

The other perception discovered during the research was the view that wheelchair users, and persons with mobility issues would be best located on the ground floor. All the designers and developers believed this was “good design practice”. Approved document M and other good design guide publications say otherwise. Where possible the increased opportunity for people with disabilities to have accommodation located at various locations throughout the hotel increases the “parity of provision” and allows individual choice. For many Architects, the challenge is trying to maintain a standard room layout that can be duplicated throughout upper floors, and can increase accommodation numbers. By carefully considering location of plant rooms, facilities, and access to green mechanical and electrical equipment, and new technologies, the shape and design of rooms can easily accommodate accessible bedrooms. By locating accessible rooms by stairs and evacuation lifts, this meant the health and safety concerns of locating accessible rooms at higher floor levels throughout the hotel was designed out.

2. NEW 2013 GUIDANCE

During this research changes to the existing 2004 Approved document M came into effect on 6 April 2013 for building work carried out in England and for excepted energy buildings in Wales as defined in the Welsh Ministers (Transfer of Functions) (No. 2) Order 2009. This did not impact on the designs, or the work already commenced on site, as this would receive an exemption, however it was interesting that when questioned, only the access consultant was aware of the forthcoming changes. This perhaps reinforces the need to ensure that designers are engaged with continuous professional development (CPD) to ensure their designs are appropriate, and that awareness of changes in legislation and guidance is better signposted.

The new documents incorporate text amendments made to reflect any changes arising as a result of the Building Regulations 2010 and 2013 amendments. There have been no amendments to the substantive requirements in Schedule 1 (i.e. Parts A to P) of the Building Regulations.

Some of the main 2013 amendments reflect changes to:

– general guidance on materials and workmanship and the Construction Products Directive

– references relating to the Equality Act 2010 and Equality Act 2010 (disability)

– simplification of general guidance for stairs and ramps (that do not form part of the external principal entrances and alternative accessible entrances

– updated guidance on access statements, door opening forces and changing places toilets

– updated guidance on guarding and handrails, and manifestation for glass doors and glazed screens moved to Approved Document K

These new amendments will ideally increase the designers heightened awareness of the need to place accessible environments as part of their thinking, and ensure inclusivity is not compromises as new sustainable technologies and iconic designs of hotels are introduced into the UK.

3. RESEARCH METHODOLOGY

The method of research undertaken included semi-structured interviews with designers, contractors and access auditors during a three month period December – March 2013 and involved stakeholders who have been involved in the design process of various planned hotels within the conurbation of the West Midlands, and London, UK.

The interviews involved nine participants, out of a group of twenty five participants who were invited to take part in the survey, and looked to evaluate the design from feasibility through to conception, and reviewed their rationale for inclusion or exclusion of accessibility, and accessible environments within their design. The respondents recognised their influences as insiders to the design process, and identified that predominately the client gave the final decision.

4. FINDINGS

Client

Participant	*Role/Position*	*Views*
1	Client – Project design manager.	Recognised the requirements of designing for inclusivity. - Not a main consideration - Positive ethos to do the right thing. - Unsure of what is a necessity in the design - Valued contributions from associated stakeholders- User groups - Relied on architect and Building control surveyors / Access auditors to provide best advice. - Believed "green issues more important" unless when it came to fire safety / evacuation procedures - Could h35 years working for the Fire Service and now as an assessor at a Local Authority. Retains contacts and relationship with the Fire Service.
2	Client (2)	Extremely interested in both "green design" and accessible design. - Recognised value of both - Positive believes - Understood requirements, and who to seek best practice advice from. Very knowledgeable in this area. - Believed in "team approach" - Recognised that accessible design can influence, but also compliment new innovative green technologies.
3	Client – Hotel chain	Extremely focussed on new technologies. Best use of space and layouts. - Believed location of site played a major impact on the design layout. - Positive believes - Appointed consultants to find "best solutions" - Believed in trying to achieve a solution but felt the hotel design is an iconic statement. Accessible design is a partial consideration. - Cost efficiencies are crucial in this "price sensitive market"

Consultants /Designers /Architects

Participant	*Role/Position*	*Views*
1	Architect (1)	Extremely engaged. Accessibility forms part of the design rationale, and she recognises that good design can ensure accessible environments can be easier accommodated in the feasibility stages. - “Good design incorporates the views of all visitors and employees of the hotel chain”. - could h35 years working for the Fire Service and now as an assessor at a Local Authority. Retains contacts and relationship with the Fire Service.
2	Consultant – Access consultant	Imperative that green issues do not impede accessibility. Both can be incorporated into the design. “Legislation recognises the challenges faced by designers, and the new 2013 documentation provides further clarity” - “Management of design –post occupancy just as important. – Same concern for green technology”.
3	Chartered practitioner	Extremely interested if adopted within building regulations Potential uses to monitor energy output, or for BREAM / energy management. Focussed on working within Client’s brief. If accessibility is part of the brief then it is considered.

Developers

Participant	*Role/Position*	*Views*
1	Private Developer -	Extremely focussed on adopted design - BIM may provide a solution. - Cost – key consideration - Potential uses throughout industry. - Competitive edge – Lean manufacturing / system build can inhibit design. - Not as high on agenda as other design considerations.

2	Developer - Private	Recognised value - Recognised “access for all” - Value to both clients, and developers on Partnership contracts. - Protection of reputation - Good design – New 2013 guidance more commercially sensitive.

5. CONCLUSIONS AND RECOMMENDATIONS

The thematic feedback from the respondents who took part in the survey was fairly conclusive and all respondents recognised that accessible environments were still an important part of “good design practice”. However 50% of the respondents felt in trying to meet client expectations for increased space utilisation, accessibility is sometimes compromised.

All respondents recognised that as clients look to reduce energy bills, and increase the use of green and sustainable technologies, a new approach to design of space required earlier consultation with mechanical and electrical designers, access consultants, and all associated stakeholders who held an interest in the design output. Most of the respondents, also believed that Building Information Modelling (BIM) would enhance the design process. The sharing of designs via electronic designs may assist in greater awareness of all consultants, and associated stakeholder’s requirements for the design. However the Architects believed they should always make the final decision on the design.

The research was very restrictive, due to the numbers of participants, and the evaluation is based on a small collective number of respondents, but the research heightened the designers need to still consider access to and use of buildings, the Equality Act, and introduced respondents to the new 2013 guidance.

The research also highlighted the issue of general awareness of inclusivity. To further expand awareness of how new technology can be introduced without compromising accessible environments, further research should be targeted at Architects, hotel chains project managers, and clients/ designers of both the public and private sector. This would increase awareness of design options, and promote harmonisation.

Following on from this research a series of CPD awareness workshops will be targeted at specific audiences. The main restriction to ensure icon designs did not impact on accessible environments was cost. If respondents adopt a positive “mindset” to this challenge further progress can be maintained, what is fundamental to the success of this challenge is the adoption of post-design management policies and procedures. If landlords, owners, and hotel chains incorporate accessibility, into their annual safety inspections, the achievement of good practice will be maintained, and the practice of creating access environments for all will be reached.

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BRITISH STANDARDS

BS8300 – Bsi - Design of buildings and their approaches to meet the needs of disabled people – Code of practice

BS 4787-1, Internal and external wood doorsets, door leaves and frames – Part 1: Specification for dimensional requirements

BS 5499-4, Safety signs, including fire safety signs – Part 4: Code of practice for escape route signing

BS 5499-5, Graphical symbols and signs – Safety signs, including fire safety signs – Part 5: Signs with specific safety meanings

BS 5839-1, Fire detection and fire alarm systems for buildings – Part 1: Code of practice for system design, installation, commissioning and maintenance

BS 6180:1999, Barriers in and around buildings – Code of practice

BS 6262, Code of practice for glazing for buildings

BS 6262-4, Glazing for buildings – Part 4: Code of practice for safety related to human impact

BS 7036-2, Code of practice for safety at powered doors for pedestrian use – Part 2: Straight and curved sliding doors and prismatic and folding doors

BS 7036-3:1996, Code of practice for safety at powered doors for pedestrian use – Part 3: Swing doors and balanced doors

BS 7036-4, Code of practice for safety at powered doors for pedestrian use – Part 4: Low energy swing doors

BS 7036-5, Code of practice for safety at powered doors for pedestrian use – Part 5: Revolving doors

BS 7594, Code of practice for audio-frequency induction loop systems (AFILS)

BS 7953, Entrance flooring systems – Selection, installation and maintenance

BS 8233, Sound insulation and noise reduction for buildings – Code of practice

BS 9999:2008, Code of practice for fire safety in the design, management and use of buildings

BS EN 81-70, Safety rules for the construction and installation of lifts – Part 70: Particular applications for passenger and good passenger lifts – Accessibility to lifts for persons including persons with disability

BS EN 115, Safety rules for the construction and installation of escalators and passenger conveyors

BS EN 179:2008, Building hardware – Emergency exit devices operated by a lever handle or push pad, for use on escape routes – Requirements and test methods

BS EN 1154:1997, Building hardware – Controlled door closing devices – Requirements and test methods

BS EN 1155, Building hardware – Electrically powered hold-open devices for swing doors – Requirements and test methods.

BENEFITS FROM THE USE OF THE KNOWLEDGE MAP IN THE CONSTRUCTION ENTERPRISE

Bożena Hoła,
Wrocław University of Technology, Wrocław, Poland, bozena.hola@pwr.wroc.pll

Marek Sawicki
Wrocław University of Technology, Wrocław, Poland, marek.sawicki@pwr.wroc.pl

Mirosław Skibniewski
University of Maryland, College Park, USA,

Abstract

The paper deals with knowledge management in the construction company. Construction companies operate in a quickly changing environment in highly competitive conditions in which customers play the decisive role. Therefore the companies need to be very flexible and be able to quickly adapt to the changing conditions. For this reason tools supporting decision making in enterprise management are sought.

Proper knowledge is required in order to carry out construction processes. The knowledge is acquired from publications, documents, legal regulations, standards and mainly from the construction projects carried out. The knowledge also resides in the employees' minds. The level of the knowledge and its range change continuously. On the one hand, the knowledge is developed and enriched with new experience, ideas and innovations and on the other hand, some of this knowledge dies out in a natural way. This is caused by staffing fluctuation, the lack of the archiving of events and the ageing of the knowledge due the constant changes in the legal regulations. The recording, storing and processing of knowledge for the purpose of drawing inferences about future projects may aid management processes to a considerable degree. The "Knowledge Map" can be used as a tool supporting decision making on the basis of the accumulated knowledge.

A Knowledge Map based on the process approach is proposed for construction companies. The benefits stemming from the use of the proposed Knowledge Map in a building enterprise are presented. The kinds of information which may be obtained from the Knowledge Map are specified and the effect of the information on making management decisions is highlighted.

Keywords: construction business, Knowledge Map, knowledge management, information processing, quality management.

1. INTRODUCTION

Numerous studies have indicated that knowledge is one of the enterprise's vital resources and investing in the skills of employees and inducing them to share knowledge bring tangible benefits. Knowledge acquisition is a lengthy process. Stores of knowledge in the form of thousands of unclassified items (data, information, experiences) may pose difficulties in their interpretation. The systematic selection of knowledge items, their verification and recording for future mapping are equally important as their creation.

An IT-based model of the Knowledge Map (KM) – a knowledge management aiding tool – has been developed on the basis of surveys carried out in Polish small and medium sized construction firms. The model uses the process approach to management, consisting in the analysis of the enterprise as a set of processes.

This paper describes the situation in Polish construction firms. A short survey of world literature on the subject highlights the importance of knowledge for the enterprise. The structure of the Knowledge Map model is presented and the thematic content of the particular knowledge domains is briefly described with reference to the benefits for enterprise management, resulting from the use of the proposed KM model.

2. PROBLEM DESCRIPTION

According to the statistical data, there are 235173 construction firms, employing in total 616420 persons, registered in Poland. In this number as many as 229899 firms are small firms employing fewer than 19 persons while 3474 are medium sized firms employing from 20 to 49 persons. This group of small and medium sized firms constitutes the basis of the construction industry in Poland.

The firms contend with many difficulties. Because of the limited investment expenditures in the firms they often lack management aiding tools (Hoła et al. 2012a). The Polish construction industry suffers from high staffing fluctuation as a result of which the experience acquired during work in a given firm dwindles as its key employees leave the firm. The means not only the loss of experience, but also of potential innovations. Consequently, great amounts of time and labour are spent reacquiring the knowledge needed for work at the particular workstations and for future construction projects.

The results of the surveys and analyses carried out in the small and medium sized construction firms in Poland indicate that the firms lack management aiding tools. It has also been found that only a few of the firms have quality, environment and work safety management systems implemented. The authors of this paper propose an IT-based Knowledge Map model as a tool aiding management in the enterprise. The principal assumption underlying the model was the combination of the Knowledge Map concept with the process approach to management. The aim of the model is to stimulate innovativeness in the enterprise, resulting in continuous improvement and the introduction of new products, services, technologies and work organization methods.

3. IMPORTANCE OF KNOWLEDGE RESOURCES IN CONSTRUCTION FIRM

In the construction industry, knowledge is one of the vital resources (Pathirage et al. 2007, Preece et al. 2000, Furcada et al. 2012). Because of the nature of building production, in the course of which difficult and challenging problems often arise and have to be immediately solved, knowledge is a needed and sought after commodity. Thus one of the enterprise's primary tasks is to uncover, locate and store the knowledge resources it possesses in order to effectively exploit this knowledge. The skilful management of knowledge may bring tangible benefits in the form of increased productivity, higher quality of the services rendered and enhanced competitiveness of the enterprise (Maqsood et al. 2006, Hamzah et al. 2012, El-Diraby and Zhang 2006, Lin 2008).

Davenport and Prusak (1998) define knowledge as a combination of data and information with experience, interpretation and inference. Nonaka and Takeuchi (2000) divide knowledge into explicit knowledge and tacit knowledge. Explicit knowledge is contained in documents and databases. Tacit knowledge is the knowledge attached to the persons who possess it. This knowledge dwindles with staffing fluctuation (Jemielniak and Kozminski 2012).

The tool for locating knowledge and aiding knowledge management is the so-called Knowledge Map (Lin et al. 2006, Yang 2007). It is a deliberately designed means enabling communication between the ones who create knowledge and the ones who use it (Wexler (2001, Lee and Tserng 2006)**.** For the enterprise the benefits resulting from the use of the Knowledge Map are substantial. Knowledge maps make it easier to find information in databases and facilitate the transfer of knowledge within an organization (Meziane and Rezgui 2004), improve the efficiency of learning (O'Donell 1994), indicate the links between documents (Xu and Ibrahim 2004) and so on.

4. STRUCTURE OF KNOWLEDGE MAP

Knowledge contained in the Knowledge Map can be ordered according to different criteria, saved in the electronic form and displayed using graphic display programs. The structure of the Knowledge map built for the needs of construction firms is shown in fig. 1. An IT-based model of the Knowledge Map was presented in the paper "Knowledge Maps for small and medium-size construction firms" (Hoła el al. 2012a, b). Seven domains of knowledge, in the authors' opinion important for the proper management of a construction enterprise, are distinguished in the proposed map. Three components of knowledge are distinguished in each of the knowledge domains.

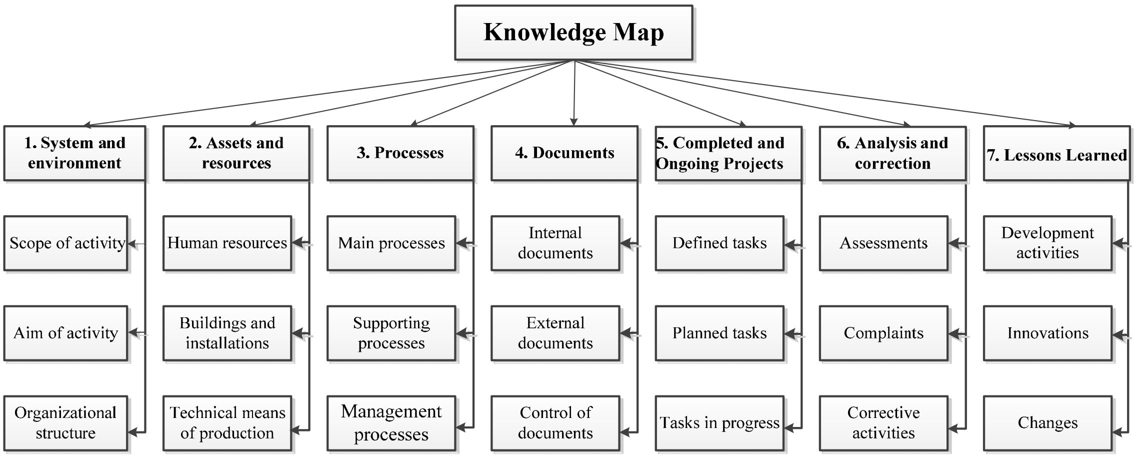

Fig. 1. Chart showing structure of Knowledge Map.

5. KNOWLEDGE ACQUIRED FROM PARTICULAR DOMAINS OF KNOWLEDGE MAP FOR ENTERPRISE MANAGEMENT PURPOSES

The knowledge contained in the particular domains of the Knowledge Map can have a confidential or public character. Interested employees may access the particular knowledge domains after logging into the system, having previously obtained authorization from the firm's management. The information contained in the particular domains can be searched according to the adopted criteria and then printed in the form of reports. This applies to the content of the particular domains and their components, process procedures, documents and the history of assessments made.

5.1. System and Environment

The *System and Environment* domain contains information about the enterprise and its business environment, stored in three knowledge components.

– The first Knowledge Map component contains basic information about the enterprise, such as: the name of the firm, its legal entity, its telephone & address data, the number of its entry on the business activity register, the taxpayer identification number, the business activity identification number, the form of taxation, the type of accounting, the type of firm (a design, contractor or design-contractor firm), descriptive information on the scope of activity, the firm's operational and strategic objectives, the firm's main documents in the form of scans or digital records (e.g. the firm's registration documents). The documents and information contained in a single file make it easier to prepare bidding documents, contracts and other documents required in contacts with authorities, institutions and customers.

– The second Knowledge Map component stores contents relating to the organizational structure of the enterprise, e.g. to the hierarchical dependencies between the particular organizational units of the firm. One can also obtain a printout of the flowchart of the firm's organizational structure.

– The third Knowledge map component contains information about the organizations cooperating with the enterprise, i.e. about the suppliers, the subcontractors, the authorities, the institutions and the clients. The information includes telephone and address data and the range of cooperation. In the case of suppliers and subcontractors, these entities can be evaluated on the basis of the history of the cooperation with them to determine whether they should be considered for future contracts.

5.2. Assets and Resources

The *Assets and Resources* domain has been divided into: human resources, tangible resources and intangible resources.

– The *Human Resources* component contains detailed information on all the enterprise's employees, i.e. record and contact details, information on the position and responsibilities held, the licenses and qualifications held, information on attended occupational health and safety training courses, medical checkups and the results of periodic employee appraisals. The information contained here is helpful in human management resources management with regard to the selection of employees for new tasks and their allocation within the enterprise, and in work safety management. An analysis of the history of the appraisals of the individual employees can be helpful when making decisions about promoting, rewarding, reprimanding or penalizing them.

– The *Tangible Resources* component contains information on the machines and equipment which the enterprise has. The information includes: the name of the tangible means, the assigned identification number (according to the enterprise classification or a general classification), information about the technical condition, the availability and workplace of the piece of equipment at a given moment and the documents connected with it, etc. Thanks to this, one can rationally manage the tangible resources and be informed about the technical condition of the equipment park components, about the condition survey dates and the availability of the particular resources in time. On the basis of this information one can create the firm's strategy with regard to the tangible resources and make the right decisions concerning the purchase or sale of the particular assets. Various schedules drawn up on the basis of the register of the possessed machines and equipment are helpful in making decisions on seeking a new order or a logistical decision. In addition, the schedules contained in this domain, combined with the costs of maintaining the above assets, enable one to estimate the indirect costs used to calculate the estimated price of construction works by the detailed method.

– The *Intangible Resources* component has a similar structure. It contains information concerning software, licences, patents, etc. The information includes the name of the intangible item, its identifier (code), the purchase date, the purchase price, the date of entry in the records, the place of storing, the present value and the person responsible for the given intangible resource.

– For each of the *Assets and Resources* components the program enables the collection and archiving of documents connected with it.

5.3. Processes

One of the major knowledge domains contained in KM is the *Processes* domain. In the activity of enterprises one can distinguish processes resulting in a value for the customer, referred to as the main, key or basic processes, and processes supporting the core activity. The range of activity of construction enterprises is very wide, covering problems relating to the design and erection of building structures. The set of processes contained in the *Processes* domain has been divided into three subsets: main processes, supporting processes and management processes. The set of main processes comprises processes relating to construction project preparation, design and implementation. The benefits for the KM user, connected with this domain are:

– This domain contains the procedures for most of the main, supporting and management processes which occur in construction firms. Each of the procedures contains information about the operations and the sequence in which they are carried out, the starting documents created in the course of an operation or a process, the persons performing the particular operations and being responsible for the whole process. It is also possible to record the execution time and cost of an operation.

– The standard process procedures are helpful in monitoring and assessing the processes being carried out with regard to their correctness, execution time and costs.

– In the case of an exchange of the employees working at the workstations, the standard procedures facilitate their training and compliance with the new requirements in the enterprise.

– It is possible to filter the processes base and to carry out various analyses. For example, one can specify the responsibilities of the particular employees for the proper running of the processes, find out which employees are overloaded or underloaded with work, determine the number of times the particular processes have been initiated and on this basis make a decision to outsource a process or allocate an additional employee to service this process.

– The processes can be evaluated with regard to the quality requirements, and the history of the evaluations can be produced for the particular processes.

5.4. Documents

The *Documents* domain has been divided into three subsets. The first subset comprises internal documents produced in the enterprise, such as: documents relating to the investment process in construction, stemming from the building code, work instructions, directives, reports, minutes from meetings, etc. The second subset comprises external documents stemming from the rules of law, such as acts, regulations and standards. The *Control of Documents* subset specifies the persons responsible for the preparation, verification, approval and storing of the particular documents. This domain plays a major role in construction enterprise management since:

– It is possible to create a single large set comprising specimens of all the documents adopted in the enterprise, which considerably facilitates and speeds up access to them by the authorized personnel. Thanks to the document specimens it is easier to generate similar documents relating to different construction projects.

– Each document includes reference to the process with which it is connected. Moreover, each document is designated with: an identifier in the form of a hyperlink to the other KM domains in which it occurs, a document name, a document type consistent with the adopted classification (internal or external), and a reference to the legal basis relating to the document.

– In the *External Documents* set one can save the current legal regulations and standards, either in the electronic form or as links to relevant web pages from which one can download the document currently binding in Poland. This considerably facilitates access to the current acts, regulations and standards relating to the investment process in Poland.

– The management of the documents is easier owing to such pieces of information as: the processes in which they occur, the current version of the document, since when it has been in force, who is preparing, verifying, approving and distributing the document, the number of copies made, which persons have inspected the document, the archiving place and period and the accessibility status (e.g. confidential).

– The information stored in the *Documents* block forms the electronically recorded archive of the firm and it can be easily processed and analyzed (this applies to all the documents or to selected groups of documents). Manual processing would take lots of time and energy and would entail additional costs for the firm.

5.5. Completed and Ongoing Projects

The *Completed and Ongoing Projects* module stores knowledge relating to the investment activity of the enterprise. The system user will find here information on the completed, ongoing or planned construction projects. The benefits from this domain for the KM user are:

– This an archive of the enterprise activities. Each executed task is described in the following way: the task name, the project owner, the planned and actual time of project execution and the characterization of the carried out project with regard to the processes and documents involved, the material and equipment needs and the necessary additional studies and expert analyses.

– The module comprises a set of ready-made models which can be used in the future to carry out the same or similar projects.

– The module facilitates the preparation of future investment processes. Using the check-up questions included in the *Planned Tasks* block one can group processes for each construction project. As a result, a set of processes involved in the fulfilment of a given customer order is obtained. Besides the processes, also the required documents and the responsibilities of the personnel taking part in the project are automatically generated.

– Knowing the project commencement date and the model durations of similar tasks one can easily draw up a schedule for the project and specify the predicted project execution time.

– The particular projects can be evaluated using the previously adopted evaluation criteria. The evaluations can form the basis for making decisions concerning the execution of similar future construction projects.

5.6. Analysis and Correction

The *Analysis and Correction* domain includes the following components: assessments of suppliers, employees and processes, complaints and corrective activities. Suppliers, employees and processes are rated in terms of quality, according to the formalized scoring method proposed by R. Kolman (Kolman 2004). The rating criteria, the weight coefficients for the particular criteria and the interval of ratings for the criteria have been specified for each of the entities. Most of the assessments are based on the data input in the preceding program blocks. For the KM user the benefits stemming from this domain are:

– The assessments made using the adopted rating methods and criteria enable one to review the human resources, the processes being carried out, the suppliers and the subcontractors in terms of quality. The ratings and their changes over time can be the basis for drawing conclusions as to corrective and repair measures which should be adopted.

– The knowledge of the filed complaints about the construction services rendered reveals the weaknesses of the enterprise and its personnel and may indicate the topics of the needed future training courses.

– The corrective measures taken as a consequence of complaints and ratings are the basis for introducing changes into the current procedures and for continuously improving the quality, effectiveness and way of construction firm management.

5.7. Lessons Learned

The *Lessons Learned* domain comprises a register of preventive measures and innovations and a component called *Changes* used to evaluate the knowledge acquired in a considered time interval.

– All achievements resulting from carrying out construction projects, individual and team experiences, ideas submitted by employees, improvement proposals, innovations and consequent changes are recorded.

– It is assumed that the submitted innovations and the preventive and corrective measures taken will prove that knowledge is created in the enterprise. Knowledge may also dwindle. It is assumed that the evidence of this will be the complaints filed. The knowledge gain in a given time interval is evaluated on the basis of the number of the above events and their weight coefficients.

– The estimated knowledge gain values are the evidence of development, stagnation or regression in the enterprise.

The development contents identified and stored in the Knowledge Map inform us whether we are dealing with a knowledge management system or an information management system. If the information has a descriptive and historic character, the knowledge relates to future situations and stems from tacit premises (Davenport and Prusak 1998).

6. CONCLUSIONS

The Knowledge Map is based on the results of surveys and analyses carried out in small and medium sized construction firms in Poland and on the process approach to management recommended in the ISO quality management standards. When it is implemented in an enterprise, the Knowledge Map will store information concerning:

– the courses of all the processes in the enterprise and the documents connected with the processes, i.e. required to initiate a process, created in the course of the process and after its completion;

– the resources which the enterprise has;

– the completed construction projects which may be used as models for carrying out the same or similar projects;

– the suppliers and the subcontractors, and especially the results of their appraisals which will be useful when selecting suppliers and subcontractors for future projects;

– employee appraisals indicating whether the employee is diligent, what value he/she represents for the enterprise and whether he/she should be rewarded.

The development activities stored in the Knowledge Map will make it possible to assess the changes in the state of knowledge in the enterprise in given time intervals, which will provide an indicator of the development of the enterprise. This research is part of an ongoing project. The IT-based model of the Knowledge Map has been implemented in two construction firms which design and carry out construction projects.

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GLOBAL VIRTUAL ENGINEERING TEAMS: CRITICAL ROLE OF DYNAMIC PACKAGE OF LEADING AND MANAGING *(DPLM)*

M. Reza Hosseini
University of South Australia, Adelaide, Australia, Mohammad.Hosseini@unisa.edu.au

Nicholas Chileshe
University of South Australia, Adelaide, Australia, Nicholas.Chileshe@unisa.edu.au

Jian Zuo
University of South Australia, Adelaide, Australia, Jian.Zuo@unisa.edu.au

Bassam Baroudi
University of South Australia, Adelaide, Australia, Sam.Baroudi@unisa.edu.au

Abstract

The construction industry has witnessed the rise of Global Virtual Engineering Teams (GVETs) as productive team structures taking advantage of members scattered around the globe accomplishing their tasks through ICTs. The desired outcomes via deploying GVETs in construction context heavily rest on meeting the requirements prescribed by antecedents and critical success factors associated with specific idiosyncrasies of GVETs. In this regard, it is widely recognized that when it comes to adopting GVETs the managerial/leadership matters are problematic. The reasons for that seem to be the limitations of ICTs as the main medium for communications exacerbated by some specific attributes of GVETs such as cultural diversity and disparity of the members. The existing literature lacks some aspects in terms of providing the construction industry with necessary knowledge on the fitted styles of managing and leading GVETs. To address this issue, this paper first aims at critically reviewing the available research on managing and leading GVETs within construction context and ascertaining the pertaining influential constructs based on an extensive literature review. This is followed by discussions presenting the necessity of addressing the challenges of managing GVETs based on a dynamic integrated approach and subsequently proposing a model, thus labeled, 'Dynamic Package of Leading and Managing' (DPLM) for Global Virtual Engineering Teams.

Keywords: Virtual Teams, Management, Leadership, Construction.

1. INTRODUCTION

Construction industry (CI) is a key contributor to the gross domestic product of most of the countries. On the other hand, the CI is not a local industry anymore due to the pressure from globalization trend. Many construction organizations specifically in developed countries are moving towards higher levels of internationalization in order to benefit from the global opportunities. In particular, many construction companies in US and Europe have transferred their operations to the developing countries, with lower running costs, and much more opportunities (Horta et al., 2013, Zhao et al., 2009).The necessity of adopting teams and methods with higher productivity has escalated due to the intention of companies to be globalized (O'Leary and Cummings, 2007) and decentralized (Algesheimer et al., 2011). As a result, many web-based methods have made inroads into the working practices of organizations within the construction industry (Abduh and Skibniewski, 2004, Nitithamyong and Skibniewski, 2011) and inadvertently have expedited diffusion of technology into working procedures (Rezgui and Zarli, 2006). One of heavily internet-relied methods in the CI is Global Virtual Engineering Team (GVETs) structure deploying scattered members while performing their jobs using internet (Joseph, 2005, Skibniewski and Abduh, 2000). Few would argue about the benefits of deploying GVETs in the CI (Hosseini et al., 2012). Hence, many engineering teams are becoming GVETs gradually (Iorio et al., 2011) and consequently we have to take into account the Critical Success Factors (CSFs) of GVETs. It is because, effective implementation of GVETs takes knowledge of their nature and the affecting variables. As per what existing studies have stated, one of the major CSFs for using GVETs concern managerial aspects stemmed from the lower quality of ICTs as the main channel for communications exacerbated by the adverse effects of cultural, geographical and temporal dispersions between the members. On the other hand, the policies and methods of management developed for traditional teams are not necessarily effective for GVETs due to the obvious discrepancies between these two systems for team working (Chen and Messner, 2010, Zakaria, 2013). Furthermore, CI has been criticized for the lack of knowledge about GVETs when it comes to comparison with other sectors of the industry (Hosseini and Chileshe, 2013, Chinowsky and Rojas, 2003). Moreover, practitioners cannot simply copy the results of the studies available in other sectors of the industry due to the obvious specific approach of the CI towards new technologies and innovations (Love et al., 2001) that necessitates providing information within its own context. On top of that, we are of the view that available studies within the construction context suffer from several drawbacks and CI is in need of creating profound knowledge to supply the industry with essential information for implementing GVETs in the working processes of construction companies. This paper will address these challenges in the CI by developing a conceptual framework as the foundation for further studies on the subject. Unlike the existing studies ignoring the dynamic nature of influential constructs, our framework takes into account the necessity of considering the comprehensiveness and dynamism of constructs affecting the leading and management aspects of GVETs building upon the results of a critical review of the literature. The paper concludes with presenting a conceptual framework comprised of packages of management policies selected in accordance to the time and the tenure of GVETs.

2. OBJECTIVES/ METHODOLOGY OF THE PAPER

The construction industry is in need of knowledge creation on GVETs. On the other hand, the first step of any study for knowledge creation should be developing new theories (Handfield and Melnyk, 1998). Likewise, as postulated by the seminal work of Wacker (1998), developing good theories requires an exhaustive literature review. In addition, using broad literature reviews as the sole method of research papers has been commonplace in the literature of virtual teams as many influential papers have built their discussion drawing upon the same methodology (Powell et al., 2004, Hertel et al., 2005). As a result, broad review of the literature seems to be appropriate fulfilling the requirements of the objectives considered for this paper. The procedure, the keywords and the resources reviewed for extracting the relevant knowledge are drawn from the recent paper by Hosseini and Chileshe (2013) encompassing extracting an inclusive array of keywords and searching within the relevant databases.

3. TERMINOLOGIES

The concept of GVETs in today's industries is the result of a lengthy evolutionary procedure (Powell et al., 2004) and still has not been fixed. Hence, due to the still evolving phenomenon of GVETs, there is no unified formal conceptual definition for GVTs in any industry including the CI (Chinowsky and Rojas, 2003). On the other hand, we need a formal conceptual definition prior to developing any framework (Wacker, 2004). As a result, we consider the below definition of GVETs within the CI as the foundation for further discussions: "Groups of geographically, organizationally and/or time dispersed intelligent workers with different skills and in different positions of the hierarchy heavily relied on ICTs to accomplish engineering tasks which for all are held accountable" (Hosseini and Chileshe, 2013, page 3). On the other hand, reviewing the limited number of available studies on GVETs within the CI revealed that researchers in the CI largely assume GVETs as the suppliers of the projects in the form of a number of offices scattered around the globe supporting the central lead office (Chen and Messner, 2010, Iorio et al., 2011). It is perceived within the CI that the former model of virtual team working would alleviate the concomitant communications and coordination issues in virtual teams (Rezgui, 2007). Therefore, this paper considers GVETs in the CI from the mentioned vantage point.

4. BENEFITS OF GVETS FOR CONSTRUCTION COMPANIES

It is not an overstatement if one says that a plethora of studies have confirmed the advantages of deploying GVETs for organizations in many industries. Major gains out of utilizing GVETs are associated with their capabilities for crossing over geographical, organizational and temporal borders (Fuller et al., 2012), cost savings (Schweitzer and Duxbury, 2010), timeliness of completion of tasks (Gressgård, 2011) and higher qualities of products and services (Gignac, 2005). All the foregoing advantages of GVETs have been confirmed by the studies in the CI on grounds of the high productivity of GVETs, their abilities to deal with recent complicated construction projects (Chen and Messner, 2010, Chinowsky and Rojas, 2003, Hosseini et al., 2012), and their capacity for adding value for organizations out of knowledge in a knowledge intensive industry such as construction (Vorakulpipat et al., 2010). Even Moore and Abadi (2005) described GVETs as a measure facilitating resolving the shortfalls of the CI echoed in the work of Egan (1998) in terms of the fragmented structure of the industry as well as meeting the requirements of the today's clients within the CI. It seems there is a consensus among the researchers indicating that GVETs have much potential to benefit the organizations within the CI and the burgeoning growth in utilizing them in organizations and projects has underpinned this stance. Obviously, lack of knowledge in the CI should not deprive the construction companies of the potential gains.

5. CSFS FOR IMPLEMENTING GVETS

Due to the specific attributes of GVETs including their dispersed structure and heavy reliance on ICTs, organizations should consider the potential issues of their implementation prior to adopting them in their working procedures. It is acknowledged by many studies that ignoring the special requirements of GVETs and failure in addressing the requirements prescribed by the CSFs would culminate in disappointing results with GVETs (Mukherjee et al., 2012). This is the case for the CI as well in which organizations might finish up dealing with teams even with less performance levels at the same time fronting more challenges (Chen and Messner, 2010, Chinowsky and Rojas, 2003). Nevertheless, as stated previously and based on the anecdotal evidences in the literature of the CI regarding GVETs, construction context has lagged far behind other sectors of the industry in terms of implementing GVETs (Moore and Abadi, 2005). In addition, studies in the CI have not kept pace with the trend of deploying GVETs within construction companies (Chen and Messner, 2010). It is acknowledged by recent studies within the CI that the area still suffers from the paucity of research on GVETs (Çomu, 2012), since there are only a handful of published works addressing the implementation of GVETs within construction context (Hosseini and Chileshe, 2013). On the other hand, similar to the agreement between the authors about the benefits envisaged for GVETs, there is consensus among the studies within the CI over the types and the nature of CSFs and antecedents for the success of GVETs. Interestingly, most of the studies have considered the same array of factors affecting the success of GVETs within the construction context. Table 1 provides a summary of the CSFs defined for implementing GVETs within construction organizations.

As shown in table 1, technical matters affect the success of GVETs. Although the literature states that technical aspects cannot be ignored when considering implementing GVETs within the CI, but due to the advancements in ICTs the infrastructure capable of meeting the requirements of GVETs seems to be available nowadays and technical aspects of GVETs are not the sources for failures in relevant projects anymore (Rezgui, 2007, Hosseini et al., 2012). It is because the technological aspects of GVETs have not been overlooked within the existing literature (Chinowsky and Rojas, 2003) and some studies have explicitly addressed the foregoing issues (Iorio et al., 2011). The other reason could be the fact that technology related challenges mostly have many overlaps with other disciplines such as IT and the results of the research within other fields are usable within construction context. Obviously, inherent idiosyncrasies of GVETs such as geographical, temporal, organizational, and cultural dispersions between members make them to be entities with managerial requirements and challenges different from the ones of face-to-face teams (Chen and Messner, 2010). As a result, above noted papers have addressed the managerial issues form GVETs and have provided the CI with guidelines and frameworks to resolve the overarching issues illustrated in table 1.

<table>
<tr><th>Main categories</th><th>CSFs for implementing GVETs</th><th>Literature backing</th></tr>
<tr><td>Technical Aspects</td><td>Provision and selection of the fitted and appropriate tools, software, and devices for effective communications/cooperation/collaboration within groups and members of GVETs</td><td rowspan="6">(Chinowsky and Rojas, 2003)

(Chen and Messner, 2010)

(Joseph, 2005)

(Hosseini and Chileshe, 2013)</td></tr>
<tr><td rowspan="5">Management Aspects</td><td>Best leadership style to address the attributes of GVETs</td></tr>
<tr><td>Effective management of communications</td></tr>
<tr><td>Fulfilling the requirements of GVETs in terms of team development including training/building trust/team identity and cohesiveness</td></tr>
<tr><td>Implementing effective methods of control and supervision</td></tr>
<tr><td>Best design and configuration for the GVET comprised of the procedure for selecting the members with compatible cultures and qualified to work in virtual environments along with defining the location, the number and the relationship maps between all the offices and members</td></tr>
</table>

Table 1: CSFs of implementing GVETs extracted from the available literature

6. RESEARCH ON MANAGEMENT ASPECTS OF GVETS WITHIN CONSTRUCTION CONTEXT

There is no doubt that the existing studies in the CI have provided the body of knowledge with valuable guidelines regarding the implementation of GVETs. Nonetheless, all these studies suffer from some drawbacks as the below:

- The number of empirical studies available within the CI focused on management of GVETs is of very limited number. Besides, they have used large US construction companies in EPC industry as the source of data. Hence, as mentioned by the authors (Chen and Messner, 2010), the results might be context-sensitive and misleading in other contexts, for other type of contracts, or in different locations.

- The definitions considered for GVETs are somehow contradictory and have apparent discrepancies. For example, Chinowsky and Rojas (2003) postulated that synchronous manipulation of data by the members is a necessary attribute for GVETs while Chen and Messner (2010) ignore this. Conversely, the latter paper only considers GVETs as the collection of scattered supplier offices supporting the activities of the lead office. The lack of a common definition in the CI research area has been confirmed within the relevant studies (Chinowsky and Rojas, 2003, Chen and Messner, 2010, Hosseini and Chileshe, 2013). Drawing upon the discussions of the paper by Wacker (2004), we argue that this situation reflects the immaturity of the body of knowledge.
- Results of the research in other fields have maintained that most of the managerial aspects of GVETs are of dynamic nature and the associated requirements alter with the time and the tenure of the team. This includes the change of skills and character of GVETs members after using ICTs for some time (Bellamy et al., 2005) which shows the dynamic nature of training requirements along with the alternations of the fitted ICTs tools and devices. When it comes to team development issues such as building trust, some studies have enunciated that trust development mechanisms change over time and are of dynamic nature (Kanawattanachai and Yoo, 2002). Nevertheless, the available studies within the CI have ignored the dynamism dominating the associated constructs.
- Obviously, all the influential constructs are interrelated and affect each other greatly. For example, the cultural background of the selected members affect the effective policies for communication management and the fitted communication channels (Bjørn and Ngwenyama, 2009). The lack of a holistic approach towards implementing GVETs within CI has been raised by the studies within the construction context (Rezgui, 2007).

Therefore, the relevant area of research in the CI is in need of creating knowledge. As a result, we should develop a framework in order to direct the future research projects as well as hastening building theories (Carlile and Christensen, 2004, Shields and Tajalli, 2006). On the other hand, it is inferred from the literature that implementing GVETs is affected by the collective effect of several dynamic constructs. Therefore, the proposed framework should be a hypothetical meta-framework showing the integrated results of all the hypotheses associated with effective constructs (Meredith, 1993) as discussed within the following sections.

7. FRAMEWORK FOR LEADING AND MANAGING GVETS

As we stated in previous sections and underpinned by the literature, technical issues are of lesser importance nowadays due to the undeniable advancements of ICTs. In view of that, we confine our discussions to address the necessary managerial aspects of implementing GVETs within the CI. Relevant literatures in the CI have considered this category of CSF as described in table 1. We consider the influential constructs to be of two broad categories, namely those with a *static* nature and the *dynamic* ones.

7.1. Static CSFs

Static CSFs mostly concern the stages involving the procedure before making the decision for adopting GVETs in projects delivered by the organization and designing the structure of the GVET. This includes two main stages as illustrated in figure 1:

I. *Stage1 (Strategic GVET planning and GVET adoption decision in the project):* GVETs implementation falls within the realm of ICTs diffusion in construction organizations (Hosseini et al., 2012). Hence, as stated by Peansupap and Walker (2005), initial stages involve strategic planning for adopting and implementing GVETs up to the point of making the decision as a crucial stage in implementing GVETs within the CI. This stage involves some constructs acting as the main issues to be considered by any organization prior to the point of deciding to adopt the GVET and embarking on designing it as illustrated in figure 1.

II. *Stage2 (GVETs Structure)*: the lead office members of the GVET are nominated and selected in alignment with the requirements of the organisation including the essential technical, managerial and leadership skills fitting the assigned tasks and the virtual environment. Organizational objectives, cost savings and the working environment conditions such as the availability of the human resources will affect the selection of members in GVETs as well. Designing the team based on the attributes of the lead office members is the next step. Members of supporting offices will be designed with a consideration of cultures and locations having the attributes compatible with the lead office members. Indeed, a strong and positive project culture helps to motivate the cooperation and collaboration within the construction project teams (Zuo and Zillante, 2005, Zhao et al., 2009, Zuo and Zillante, 2006). This stage should be pursued considering all the factors affecting the establishment of a coherent team capable of settling conflicts and develop trust internally as well. In addition, considerations such as the minimum legal risk, visa requirements and diplomatic relationships between the associated countries of the offices should be taken into account.

7.2. Dynamic CSFs

As discussed in previous sections, several constructs of managing and leading GVETs are literally of dynamic nature while being affected by other constructs since they all correlate internally. It is because as GVET proceeds in its lifecycle, the associated requirements such as the model and mechanism of effective communications and team development policies alter gradually (Lumsden et al., 2009). If we consider all the managerial and leadership policies associated with different issues and constructs, the tasks of GVETs' managers would encompass selecting the fitted package for consecutive timely cross-sections. It is beyond the scope of this paper to discuss the package components in detail. However, we have illustrated the dynamic constructs of the packages in figure 1 showing the considerations the managers of GVETs should take into account when selecting the best package. Likewise, the elements of each package should involve the fitted managerial policy and leadership style effective for addressing the thereof requirements in the time of interest.

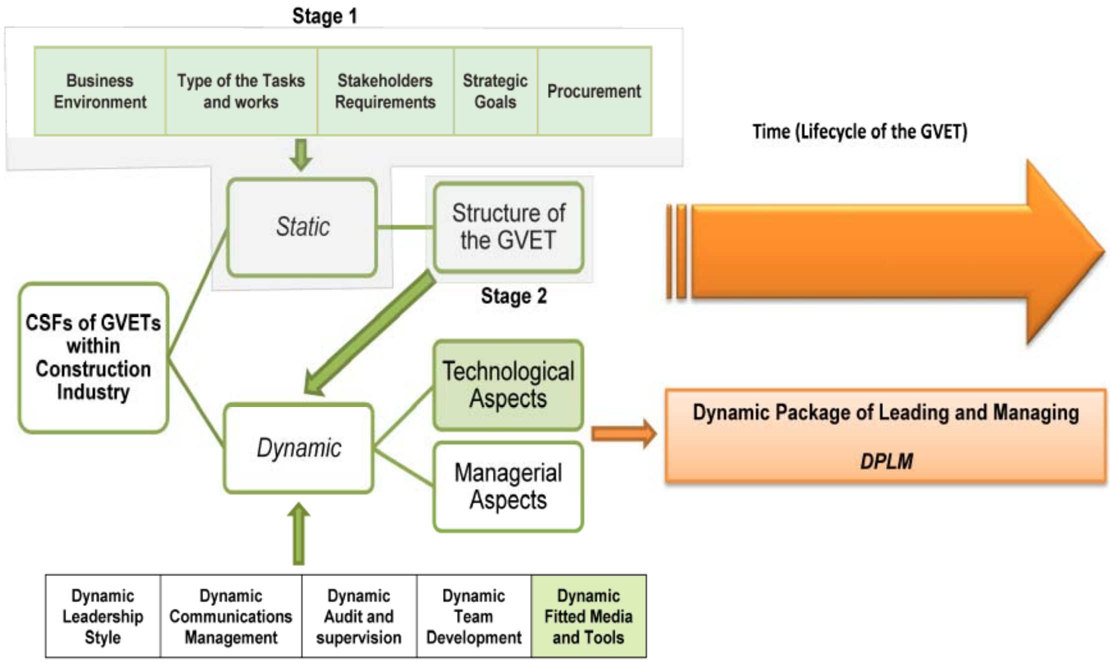

Figure 1: The Dynamic Package of Leading and Managing' for GVETs (DPLM)

As a result, the elements that comprise each package of management and leadership of GVETs are as the below items:

- The fitted media including tools, devices, software and communication channels as illustrated in figure 1 in boxes in same colors showing the relationship with technological aspects
- Most appropriate leadership style for the conditions of the GVET
- Supervising and control strategy fitting the members, leadership attributes and the medium and communications management policies selected
- Communications management policies meeting the requirements of the selected members and limited by the media, leadership style and attributes of the members
- Team development policies defined by all the above conditions dominating the GVET

8. CONCLUSIONS

The literature review showed that there are some specific requirements as the prerequisites of success for GVETs including the necessity of implementing effective managerial and leadership strategies for GVETs. However, the managerial policies developed for face-to-face might not necessarily be effective in GVETs. In addition, the literature review revealed the shortcomings of available body of knowledge concerning the above noted matters in the CI. Hence, we developed a working hypothesis in format of a conceptual meta-framework reflecting the constructs of managing and leading GVETs within the CI effectively. Our meta-framework was developed based on considering the management and leadership requirements of GVETs as a process of dynamic packages selection. This would provide the future researchers with a fruitful ground since the previous studies have considered all the managerial and leadership aspects of GVTEs as isolated concepts and have addressed them separately without considering their interrelations. The future research is required on selecting the best management and leadership policies through the lenses of a holistic approach. All constructs affecting GVTs are correlated matters influencing each other and the whole system as well. For that reason, future research opportunities exist to clarify on the correlations between the constructs affecting the performance of GVTEs. As many of the constructs are from multiple disciplines, it is imperative to consider a multidisciplinary approach towards selecting the best strategies of managing GVETs in future research studies. This includes taking into account the effects of innovation diffusion, change management, knowledge management and other management systems as an integrated management system. Validating the framework presented and empirical investigations on the veracity of the constructs and ascertaining variables making up the constructs are other grounds available for further investigation as well.

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STATE OF RESEARCH ON GLOBAL VIRTUAL TEAMS (GVTS): A COMPARISON BETWEEN CONSTRUCTION AND OTHER INDUSTRIES

M. Reza Hosseini
University of South Australia, Adelaide, Australia, Mohammad.Hosseini@unisa.edu.au

Nicholas Chileshe
University of South Australia, Adelaide, Australia, Nicholas.Chileshe@unisa.edu.au

Jian Zuo
University of South Australia, Adelaide, Australia, Jian.Zuo@unisa.edu.au

Bassam Baroudi
University of South Australia, Adelaide, Australia, Sam.Baroudi@unisa.edu.au

Abstract

The rapid developments of internet-based technologies have paved the way for the rise of novel structures for teams. Consequently, last decades have witnessed the burgeoning rise of Global Virtual Teams (GVTs) perceived as an effective, efficient, and creative team structure taking advantage of talented members scattered over different geographical locations and time zones utilizing ICTs as the central media. Earlier studies have reported successful GVTs projects within different industries along with forestalling an inevitable growing trend for using GVTs as a part of future organizations' structures. Nevertheless, achieving the numerous benefits envisaged for GVTs, takes an in-depth appreciation and awareness of the various specific critical success factors and the pertaining antecedents. On the other hand, the lack of research in construction context seems obvious. This study builds the discussions on the assumption of regarding the adoption of a GVT in an organization as a very isolated project. Afterwards, key corresponding phases, necessary knowledge areas and requirements of managing a GVT as a project will be highlighted. With respect to defined aspects of managing GVTs, the study will compare the cutting-edge knowledge available from the literature in other industries with that of the construction context. Accordingly, a research agenda is proposed to define the directions of necessary research on GVTs within the construction industry.

Keywords: comparison, construction, research, virtual teams.

1. INTRODUCTION

To address the challenges of today's business environment, construction literature has observed the publication of many treatises geared towards increasing the level and effectiveness of harnessing different innovations such as Information Communication Technologies (ICTs). Accordingly, different web-based techniques have permeated into the working routines of organizations in construction context (Abduh and Skibniewski, 2004, Nitithamyong and Skibniewski, 2011). Subsequently, a subset of ICTs innovations namely the team structure in which members of the team are located in different geographical areas has become increasingly commonplace in many organizations active within the construction context (Peansupap, 2004, Becerik-Gerber et al., 2012). Thus, construction industry is witnessing the emergence of Global Virtual Teams (GVTs) treated as effective, efficient, and creative service providers for construction organizations. There is a wide spread consensus over the advantages of deploying GVTs in the construction industry (Hosseini et al., 2012) and many teams active in construction industry are becoming GVTs gradually (Iorio et al., 2011). However the desired outcomes via deploying GVTs are heavily reliant on meeting the requirements prescribed by critical success factors associated with inherent idiosyncrasies of GVTs (Chinowsky and Rojas, 2003). There are evidences postulating that around half of failures with GVTs are stemmed from the manager's lack of knowledge of the specific requirements of GVTs (Schweitzer and Duxbury, 2010). Nevertheless, the body of knowledge on utilizing GVTs in general (Martins and Schilpzand, 2011, Schweitzer and Duxbury, 2010) and specifically in construction context is not mature enough (Hosseini and Chileshe, 2013a, Chinowsky and Rojas, 2003). It gets worse taking into account the sociological and personnel aspects of web-based methods (Nitithamyong and Skibniewski, 2007). Based on the above problem statement, this paper is geared towards underlining the necessities of future research on GVTs in construction context by making comparisons with the cutting-edge knowledge available in non-construction sector.

2. METHODOLOGY

Building on the results of exhaustive literature reviews as the sole method has been deployed in seminal papers concerning GVTs (Powell et al., 2004, Hertel et al., 2005). The extensive review of the existing literature focused on certain criteria seems to fit with the objectives of this paper thus used as the primary source of information and the sole method deployed. To access the existing body of knowledge pertaining the subject of interest, approaching the appropriate databases is of crucial importance (Green et al., 2006). Hence, we searched within a wide range of databases including Google-Scholar, Elsevier, Emerald, ISI web of science, Science-direct, Compendex, EBSCO, and ABI/INFORM. Along with all well-known databases we covered some private bibliographic databases e.g. http://www.scoop.it/t/virtual-r-d-teams as well. We included the titles and labels presented in previous papers by (Martins and Schilpzand, 2011, Hosseini and Chileshe, 2013a) as the keywords for our research. The search led us to around 400 journal papers, dissertations and conference papers concerning GVTs from which less than 20 were from construction industry.

3. CONCEPTUAL FRAMEWORK

As implied by Whetten (1989) the fundamental building block of any knowledge creation attempt should be a model clarifying the constructs and the relationships that explain the subject of interest. As per our previous discussions, the research field on GVTs is in need of creating knowledge, thus a framework needs to be established for directing the further research and discussions (Carlile and Christensen, 2004). With some input from Hertel et al. (2005) and drawing upon the framework used in (Hosseini and Chileshe, 2013a) the key areas reflecting the necessary knowledge on GVTs were incorporated in the conceptual model illustrated in figure 1. This conceptual model considers the necessary knowledge on GVTs by assuming that managing a GVT is an isolated project. Accordingly, the model pigeonholes all the corresponding activities and associated knowledge in four main categories including defining the concept, initiating, execution and relevant activities, and closing the GVT. The four categories cover major essential managerial knowledge and incorporate all the stages from agreeing on the concept of GVTs and its attributes, adoption decision making, and actual implementation. This process continues to the end of the project and the juncture of decision making about the future of the GVT. It is noteworthy to mention that presumably implementing GVTs is an innovation as a subset of ICTs diffusion in construction projects (Peansupap, 2004, Hosseini et al., 2012). Hence, the procedure in conceptual framework is designed in alignment with the stages of implementing innovations in construction industry developed by Slaughter (2000). In addition, the conceptual framework complies with the process of ICTs implementation in construction industry proposed by Peansupap and Walker (2005) as shown in figure 1. The foregoing consistencies denote the validity of parsimony and comprehensiveness of the conceptual framework for investigating the necessary knowledge areas for deploying GVTs according to Whetten (1989).

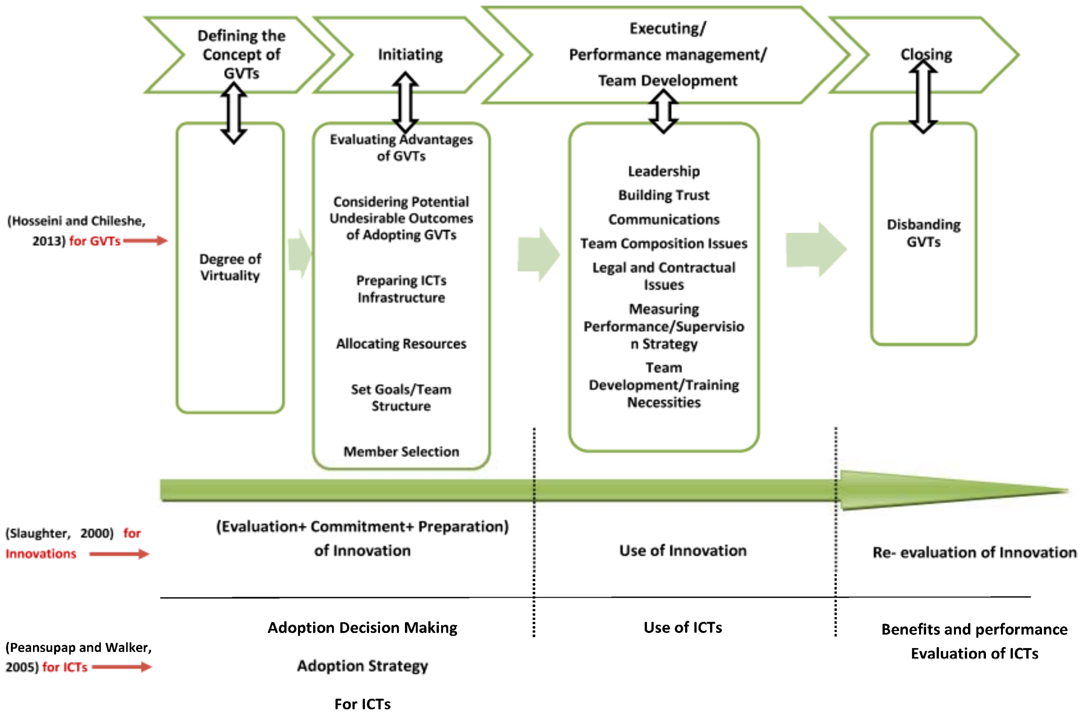

Figure 1: conceptual framework for delineating the necessary knowledge for GVTs implementation

4. COMPARING THE STATUS OF RESEARCH

The foregoing areas illustrated in the conceptual framework (figure 1) highlight the grounds of comparison between the states of research on GVTs in construction context with other sectors of the industry as discussed in the following sections.

4.1. Defining the concept of GVTs

As a very simple definition, Peters and Manz (2007) defined GVTs as teams with members located in more than one location working extensively with computer-mediated tools as the main channel of communications. Yet, the conceptual definition of GVTs is still evolving and the literature has not yet introduced a stable terminology (Powell et al., 2004, Martins and Schilpzand, 2011). Therefore, a unified agreed-upon conceptual definition for GVTs literally does not exist within the literature. In addition, many constructs of the available definitions suffer from ambiguity and vagueness e.g. the extent of dependency on ICTs (Martins and Schilpzand, 2011, Schweitzer and Duxbury, 2010). Accordingly, researchers have attempted to describe the conceptual definition of GVTs more clearly by utilizing new approaches such as the concept of degree of virtuality of teams drawing upon the dimensions of virtuality. Degree of virtuality concept could be regarded as the most advanced approach towards conceptual definition of GVTs. To the best of our knowledge all the studies in construction literature except for the work of Hosseini and Chileshe (2013a) have neglected the degree of virtuality for GVTs e.g. (Chinowsky and Rojas, 2003, Rezgui, 2007, Zhang et al., 2007, Chen and Messner, 2010). Hence, construction context researchers have utilized the traditional definition approach for defining GVTs ignoring the shortcomings. Chen and Messner (2010) argued that the available definitions of GVTs have the potential to incorporate the general features of GVTs. Nevertheless, the authors of the mentioned paper pointed out that construction literature requires a conceptual definition able to reflect the idiosyncrasies of the construction industry as stated later by Hosseini and Chileshe (2013a)

4.2. Initiating

Evaluating advantages of GVTs/Considering potential undesirable outcomes of adopting GVTs:

Initiating is the phase during which the project management decides regarding adopting GVTs in the project. Obviously, this decision should be made by utmost caution having a deep appreciation of all the conditions of the project along with advantages, drawbacks, and associated risks of GVTs. Full awareness of the following areas during the initiating phase of implementing GVTs in a construction project is a perquisite in construction industry (Chinowsky and Rojas, 2003). Presumably, advantages of GVTs act as the main driving forces behind adoption of GVTs within different industries (Hertel et al., 2005, Camarinha-Matos et al., 2005) . The positive points mentioned, included the ability of GVTs in overcoming geographical and time boundaries (Powell et al., 2004), profits due to lower wages (Hunsaker and Hunsaker, 2008), the cut of office space costs, and decreased travel expenses (Schweitzer and Duxbury, 2010). Construction studies have affirmed the above noted aspects as the advantages of using GVTs in their projects. However, the main motive for construction industry seems to be the higher productivity levels of GVTs (Chen and Messner, 2010, Chinowsky and Rojas, 2003) and their abilities to create value out of knowledge management (Vorakulpipat et al., 2010). Nevertheless, some reports from other disciplines have warned about the lower productivity of GVTs in some cases (Duarte and Snyder, 2006, Monalisa et al., 2008), which necessitates in-depth assessment of the benefits and drawbacks of GVTs in construction industry. However, few studies have investigated the effectiveness of GVTs within construction context (Rezgui, 2007). It is inferred that there is a common belief in construction literature regarding the benefits of GVTs. It is not a surprise, as an excessively optimistic impression is attached to the concept of any innovation such as GVTs within the construction industry literature. This positive perception leads to overlooking the risks and challenges of deploying GVTs due to the changes necessary for implementing any innovation in a construction projects (Sexton and Barrett, 2003). This is the case specifically for GVTs as they are highly dependent on socio-organizational factors of projects (Rezgui, 2007).

Preparing ICTs Infrastructure:

There is the consensus among the researchers that GVTs cannot operate and even will not exist excluding ICTs from their procedures (Peters and Manz, 2007). This belief is acknowledged by construction studies as well (Peansupap, 2004). However, ICTs acceptance of construction industry is still a matter of debate and in need of further investigation to resolve the cultural issues facing construction practitioners (Hosseini et al., 2012).

Allocating resources/Set goals/Team structure/Member selection:

One of the primary steps in initiating stage of adopting GVTs is determine the most fitted structure for achieving the goals that should be defined earlier as stated by researchers of many disciplines (Hertel et al., 2005, Schweitzer and Duxbury, 2010) including construction (Abuelmaatti and Rezgui, 2008). Specifically, cultural issues of GVTs should be addressed in order to tackle the issues that often exist in construction projects, especially in international level (Zuo and Zillante, 2006) which is largely applicable to GVTs attributes. Nevertheless, existing studies from construction industry suffer from paucity of research on investigating the correlation between the structure of the GVT and the objectives of the project. Even as stated previously in this paper, the knowledge about the conceptual definitions and variables affecting structure of GVTs are not mature enough in construction literature. Similarly, issues concerning the selection of members of GVTs have been overlooked within construction context in comparison to manufacturing or business disciplines. It seems that when it comes to initiating phase specifically comparison of advantages and drawbacks of GVTs, “construction industry severely suffers from the lack of relevant studies” (Hosseini and Chileshe, 2013a, page 6).

4.3. Execution/ Performance Management/ Team Development

Leadership:

Areas presented in this overarching category cover the necessary knowledge that a project manager should demonstrate in order to implement and operate a GVT effectively. Most of these areas of knowledge (see figure 1) focus on the management and leadership of GVTs. The reason for this emphasize is the fact that the style of management and leadership of GVTs is not necessarily similar to that of traditional teams (Hosseini and Chileshe, 2013b). Even, implementing managerial policies of traditional teams for GVTs could be misleading in some cases (Schweitzer and Duxbury, 2010). Most of the areas of knowledge defined suffer from ambiguity in non-construction disciplines. In case of leadership, many researchers have maintained that leadership has a crucial effect on effectiveness of GVTs and is among the primary issues of managing GVTs e.g. (Hertel et al., 2005, Malhotra et al., 2007). Contrarily, results of some studies showed that GVTs performance is not affected by the style of leadership in GVTs (Goh, 2010). When it comes to construction context, one comes across few studies addressing leadership as an element of the framework for managing GVTs (Chen and Messner, 2010, Chinowsky and Rojas, 2003). We argue that the knowledge on GVTs leadership in construction projects is still in need of further research given the lifelong controversy over the phenomenon of leadership in construction management (Toor and ofori, 2008).

Building trust:

Building trust amongst the members of GVTs is one of the most frequently addressed issues of GVTs in existing studies in non-construction industry. Nevertheless, ascertaining the best methods of building trust in GVTs in construction industry in different phases of the GVTs' lifecycle is still in need of further investigation (Hosseini and Chileshe, 2013a).

Communications/Team composition issues:

Construction is an information and communication based business (Vorakulpipat et al., 2010, Rezgui, 2007) considering the amount of information generated and exchanged during a project lifetime. Yet, although there is plethora of research on this topic in non-construction context (Hosseini and Chileshe, 2013a), we did not come across any study focused on the issues of GVTs communications management in construction literature. Thus, future research on the following matters would contribute noticeably to the knowledge about GVTs in the construction industry. Presumably, issues of communication are exacerbated by the cultural diversity of GVTs as an inherent attribute of GVTs composition and are in dire need of further investigation.

Legal and contractual issues/ Measuring performance and supervision strategy/ Team development and training necessities:

To take advantage of GVTs, managing contracts and legal issues is a prerequisite (Arenas et al., 2008). Nonetheless, the construction industry has obviously overlooked the legal matters except for the work by Abuelmaatti and Rezgui (2008). Lack of an appropriate method for measuring performance and exercising supervision in GVTs is one of the challenges facing researchers in non-construction context (Camarinha-Matos et al., 2005). This field suffers from paucity of research in construction industry literature as well. The dramatic effects of GVTs development on its performance is acknowledged in many seminal studies from wide range of disciplines (Hertel et al., 2005, Powell et al., 2004) which logically would be the case in construction industry. However, this area is still in need of further investigation given the specific requirements and attributes of construction industry.

4.4. Closing (Disbanding GVTs)

The process of disbanding GVTs takes careful planning to maintain the motivation and cohesiveness of the team during its operation. Yet, issues related to closure or disbanding of GVTs are literally neglected in empirical as well as conceptual studies (Hertel et al., 2005). Likewise, lack of research on the forgoing issues is evident in construction context (Hosseini and Chileshe, 2013a).

5. DISCUSSIONS

We summarize our discussions based on the framework defined by Sandberg and Alvesson (2011) for spotting the gaps of knowledge in the existing literature. Table 1 presents a comparison between the knowledge available in construction industry with that of non-construction context. It also highlights the gaps of available knowledge in the construction industry literature based on three basic gap-spotting modes namely *confusion*, *neglect* and *application*. *Confusion* is the case when the knowledge on the matter exists whilst the views are contradictory, competing and somehow confusing. When we cannot find adequate amount of research on an issue or the cases when the existing knowledge has overlooked a matter, we face the mode of *neglect*. It is the neglecting mode as well when an issue is still under investigation or no adequate empirical evidence is available to support the hypothesis presented. When the existing knowledge of an area is in need of extending, complementing, or amendments it falls within the realm of *application* gap-spotting mode (Sandberg and Alvesson, 2011).

Table 1: comparison between research on GVTs in construction and non-construction industries with input from (Hosseini and Chileshe, 2013a)

Areas of Knowledge	Non-construction literature	Construction Literature
Conceptual definition	*Confusion+ Application*	*Confusion+ Application*
Theoretical definition of virtuality concept	*Confusion+ Application*	*Neglecting (overlooked)*

Comparing the advantages and disadvantages of GVTs	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
ICTs as the main communication channel	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Team designing	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Leadership	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Building trust	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Communications management	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Team composition issues	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Legal and contractual issues	*Neglecting (overlooked)*	*Neglecting (overlooked)*
Performance/ Supervision	*Neglecting (under-research)*	*Neglecting (overlooked)*
Team development strategies	*Confusion+ Application*	*Neglecting (under-research+ Lack of empirical support)*
Disbanding GVTs	*Neglecting (overlooked)*	*Neglecting (overlooked)*

As evident from table 1, many areas of knowledge necessary for implementing GVTs suffer from paucity of research and in some cases are neglected in the construction literature. On the other hand, there are evidences postulating that around half of failures with GVTs are stemmed from the manager's lack of knowledge about the requirements of GVTs (Schweitzer and Duxbury, 2010). Considering the foregoing discussions, further investigation regarding aspect of GVTs illustrated in table 1 seems imperative. It is because the knowledge areas defined provide the project managers with essential competencies for the success of any project with GVTs. Nevertheless, it is obvious that construction industry literature in its current state is not able to provide the industry with necessary knowledge. As a result, setting an agenda for future studies in construction context seems necessary as presented in the following section.

6. CONCLUSIONS

Future researchers should attempt to expound on all the areas of knowledge necessary for managing GVTs in construction context. This should be based on an integrated approach to assist the construction project managers in overcoming the inherent challenges of GVTs exacerbated by the specific idiosyncrasies of the construction industry. Nevertheless, having such integrated all-inclusive knowledge necessitates creating knowledge on GVTs to answer the following questions:

1. What should be the unified conceptual definition of GVTs in construction industry? (What are the constructs affecting the virtuality of teams? How these constructs interact?)

2. What is the framework for evaluating the effectiveness of implementing GVTs in different construction projects before adoption and during the actual implementation stage?

3. What could be an effective framework for addressing all the issues of managing and leading GVTs including all the necessary areas of knowledge for managing a project? (This should include all the areas of knowledge such as communications management, human resources management, auditing, risk management, integration management and all the areas necessary for managing an isolated project (Project Management, 2008))

In addition, as we stated, construction literature has paid noticeable attention to innovation implementation and diffusion of ICTs. Although GVTs fall within the realm of both previous areas of research, researchers have defined no link between these three areas. Therefore the fourth item of our agenda would be:

4. How can we integrate the fragmented knowledge available on GVTs, building upon the theories developed for innovations, web-based project management, and ICTs diffusion within construction industry in order to fill the gaps of knowledge on GVTs?

We are of the view that proposed areas for future research studies will form the building blocks of a robust body of knowledge on GVTs for the construction industry.

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THE BUDGET OF THE MODERN COLUMN FORMWORK BY A CALCULATION BASED ON NEW NORMS

Zsolt Huszár
Budapest University of Technology and Economics, Faculty of Architecture, Hungary,
zshuszar@ekt.bme.hu

Abstract

Since the market of the building-trade has become tighter, and the building projects have been reduced, the precise planning of the future projects' budget has become more important. One of the most significant parts of this process is making the precise budget of the design work, to know the probable costs of the project and also the applicants can give more competitive offers. The key to a precise budget is correct pricing, which cannot be achieved without using a suitable norm. Since 35-40 percent of the building constructions are the formworks it is worth reconsidering the basis of the norm we are using.

The purpose of this article is to examine and compare the modern column formwork's traditional norms – based on square meter – with the new ones, based on calculating per piece. The first measured data are regarded to the building construction. The goal of this essay is to prove that when planning the budget it is more accurate to use one piece of column formwork as a unit than one square meter. With that method we get a more reliable calculation of the final costs.

Keywords: budget, norm, column formwork, final cost

INTRODUCTION

The first question arising is, what is the budget for, who is the one creating it and how can one have it accepted by the market. Of course, the answer is that we want to know the expectable value of the building or engineer construction being important not only for the principal but it may also be a factor influencing the decision making on the side of the designer and the manufacturer. In addition, a well prepared budget provides not only the cost price but it specifies itemised designer's instructions concerning quality and technology; these instructions are not necessarily included in the plans and technical descriptions. However, the questions what the points making a budget successful are and how the application of the norms used in them influence the designer and bidder prices are rarely put. This issue may be of vital importance for public procurement tenders, where a given system of norms should compulsorily be used influencing fundamentally the total price. Present paper analyses a specific system of norms, i. e. the one used to modern buttress shuttering applied to the construction of reinforced concrete structures and its method of calculation.

SYSTEM OF NORMS

The older Maintenance Construction Guidelines (FÉMIR) and the developed version of the new Construction Industrial Technical Guidelines (ÉMIR) have embodied the Uniform Construction Industrial System of Norms (ÉN) elaborated by TERC Kft. and published in 1994 and its Small-Plant version (ÉNK). In addition to the reconstruction works, these norms extend to the construction of new buildings and constructions and – surpassing the competence of the older collections of norms – they contain resource values for the construction/assembling works needed frequently to the construction of communication and water management objects as well.

The building products, the technological development, the wide range of building materials appearing in the Hungarian market as well and, not in the last place, the admission of Hungary to the European Union in 2004 have required the development of the bulletins and the elaboration of up to date collections of systems of norms complying with the Union's directives. Due to the structural changes having taken place following the social transformation and the requirements of the players of the construction industry, the development and publication of collections of norms specifying different resource values due to different environments of undertaking (company, small-works) interested in the same operation have become unnecessary. The development of the items and options of the collection of norms for small-works (ÉNK) and its publication were stopped. The new system of norms – in compliance with the above requirements – was named: Assembled Construction Industrial System of Norms (ÖN).

ÖN SYSTEM OF NORMS

According to the general rules of accounting, as a vertical structure, the shuttering being in contact with the concrete will be calculated in square meters. Basically, the ÖN system offers two kinds of shuttering; the traditions wooden shuttering with supporting structure and the assembled panelled shuttering with supporting structure. The wooden shuttering should be divided into classic board-covered romenade buttress shuttering supported with wooden beams and wooden-beam type of shuttering with multi-layer shuttering shell panel surface well known for floor shuttering systems. For both cases the appropriate unit to measure the resource norm is h/m2, i. e. the basis of accounting is the surface contacting the concrete. The ÖN system applies the following terms to identify the activities for this type:

Column shuttering with wooden shuttering of constant square cross section with support up to a height of 3 m and 60 cm lateral size, norm: 1.35 h/m2

Column shuttering with wooden shuttering of constant square cross section with support up to a height of 3 m and 60.01 - 100 cm lateral size, norm: 1.00 h/m2

Column shuttering with wooden shuttering of constant square cross section with support up to a height between 3.01 – 6 m and above 100 cm lateral size, norm: 1.58 h/m2

Let's check the case of a modern buttress shuttering. In case of modern buttress shuttering, the buttresses can be categorised as follows.

a; Made of framed wall shuttering, but of universal elements which can be joined not only at the corners and the edge of the panels, but the panels are densely perforated in full width, using generally 5 cm raster.

b; Made of framed wall shuttering, with traditional, normal panels, but using auxiliary moment-resistant buttress belt connections.

c; Wooden beam buttress shuttering, the structure of which is the same as the one of the above mentioned wooden beam wall shuttering system.

Analysing the three basic buttress shuttering systems, the only one system to be assigned to the traditional, old m2 accounting system used in the old norms, is the wooden-beam type. In this case, following from the construction technology of the system, the lateral size of the buttress equals to the size of the surface to be concreted, i. e. buttress panels of different element sizes should be applied to buttresses of different sizes and cross sections. It means that the basis of the accounting is the covered surface m2. The ÖN system applies the following terms to identify the activities for framed buttress shuttering:

Column shuttering with square, assembled panel of fixed cross section, moved manually, with support, up to a height of 3 m and lateral site of 60 cm, norm: 1.15 h/m2

Column shuttering with square, assembled panel of fixed cross section, moved manually, with support, up to a height of 3 m between lateral sizes of 60.01 – 100 cm norm: 1.27 h/m2

Column shuttering with square, assembled panel of fixed cross section, moved manually, with support, between heights of 3.01 – 6 m above a lateral size of 100 cm norm: 0.53 h/m2

In case of framed systems the ÖN offers the option of leasing by square meter size or term of lease, but both parameters can not be specified at the same time. This is a hard-to-construe situation and our present study does not extend to its analysis.

CHECKING AND MEASURING THE NORM:

Comparing the system of norms of the wooden-beam buttress shuttering with the assembled-panel, so called modern one, the situation becomes more complicated. Generally, independently of brand, there are two basic types of buttress shuttering within the assembled systems. The first one applies special, so called variable panels to create the buttress shuttering; the panels can be connected not only at the corners, but they are perforated densely, in 5 cm raster and can be joined in arbitrary width what means that a buttress of 20 x 20 size can be made of an element of e. g. 75 cm width or even buttress shuttering of 60 x 60 cress section can be made using the same panels. Similar result can be achieved with the other type of assembled panel buttress shuttering with the difference that while the buttresses are assembled with the elements of the classic wall shuttering, the corner connections are solved with adjustable moment-resistant connection buttress belt. Again, buttress shuttering systems of various cross sections can be created using the same panel size. In the system of norms used presently, these modern variable buttress shuttering systems should be interpreted in square meter system. It means that, if for the lower levels buttresses of 60 x 60 size will be made, and 30 x 30 for the upper levels, the present system of accounting results in a double labour or leasing cost for the same shuttering, although the same m2 size can be shuttered for both types of buttress in unit time. This situation will be studied for a specific construction project; what differences can be encountered between the traditional m2 and the item-based norm calculation introduced by me. The building under review is a buttress framework building of approx. 400 m2 floor-space; 8 floors, 3 levels of deep garage of them. The characteristic cross section is 30 x 30 cm except for the basement levels, where the average size is 80x30 cm. Concerning the heights of the buttresses under review, two different heights can be distinguished, as the norm specify, below 3 m and between 3 and 6 m. For the building mentioned above the characteristic height group was below 3 m with the exception of the first basement level deep garage and the ground-floor floor-level buttresses. During the entire duration of the construction, the time required by the shuttering and the daily headcount of the engaged workers were analysed. As a result of this measurement, the classic norm values and the new h/piece norm values calculated from the time of manufacturing of the individual pieces were calculated. These data are summarised in Table 1. as measured initial data.

Formwork level	**-3. level**	**-2. level**	**-1. level**	**Gr.floor**	**1. floor**	**2. floor**	**3. floor**	**4. floor**
New norm h/pc	5,33	5,33	9,78	8,33	5,33	5,67	5,00	6,00
Measured norm h/m2	1,35	1,35	1,67	2,12	1,60	1,70	1,54	1,67
Working hour/day	8	8	8	8	8	8	8	8
worker	6	6	11	25	16	17	15	6
Working day	3	6	6	6	6	6	6	6
Cross section (cm)	80x30	80x30	80x30	30x30	30x30	30x30	30x30	30x30
Columb	9	9	9	24	24	24	24	8
Height (m)	< 3,00	< 3,00	3 <H< 6	3 <H< 6	< 3,00	< 3,00	< 3,00	< 3,00
m2	35,5	35,5	52,56	94,5	80,1	80,1	77,8	28,8

Table 1.

Table 2. contains the labour costs for one m2 and the piece-based norms pursuant to the new system using the presently accepted overhead hourly pay of HUF 2 500.- to both cases. Of course, the actually used ÖN norms are also displayed in the table with the m2 based norms. Thus, the expected labour costs were calculated by three different system of norms and the following results could be gained. As early as at the first table it was yet obvious that the measured m2 based norm data have exceeded the values specified by ÖN for both heights of shuttering resulting in higher labour costs. The same is valid for the labour costs calculated from the norms basing on the number of buttresses, but the calculated values have even exceeded the ones calculated by the m2 based measured norms. It means quantitatively that while the labour costs calculated by the measured m2 based norms have exceeded the ones implied in the ÖN system by 11 %, the piece based labour costs were higher by 14 % than the results coming from the ÖN system.

Name of the item	Sum m2	Sum piece	Norm h/m2		Norma h/pc	Labour costs (Ft)		
			ÖN	Measured data	Measured data	Based ÖN	Based on measure-ment h/m2	Based on measure-ment pc/m2
Column shuttering up to a height of 3 m	337,8	98	1,38	1,53	5,44	1 165 410	1 292 085	1 332 800
Column shuttering between heights of 3.01 – 6 m	147,06	33	1,58	1,9	9,06	580 887	698 535	747 450

Table 2.

SUMMARY

Of course, no well founded conclusions can be drawn from the measurement values for one building, but it can clearly be seen that the values provided by the traditional m2 based system of norms for buildings constructed with up to date shuttering need to be revised, because deviations exceeding 10 % may result in serious financial consequences. To see whether the transition to a piece based system is useful, several buildings must be measured, but we still can think of the benefits and disadvantages resulting from the differences encountered. If the cost writer is the designer specifying a m2 based system, the manufacturer will be under-priced and this situation will probably be felt right before the post-calculation starting the shift of the losses to the sub-contractors initiating chain reaction.

SELF ADAPTIVE FORECASTING FOR CONSTRUCTION PROJECTS

Magdy Ibrahim
Concordia University, Montreal, Canada, m_omari@encs.concordia.ca

Osama Moselhi
Concordia University, Montreal, Canada, moselhi@encs.concordia.ca

Abstract

This paper presents new techniques for trending and forecasting in construction. The proposed methods can estimate the project cost at completion or at any intermediate time horizon with good accuracy. Unlike current applications of the EVM method, the proposed method uses algorithms which improve accuracy of forecasting and dynamically reduce forecasting errors. The trending algorithm is based on a popular technique used in stock markets' trading. Moving average is one of the most popular and often-used technical indicator in price forecasting of stocks. The moving average is easy to calculate and, once plotted on a chart, is a powerful visual trend-spotting tool. The application of the moving average technique removes random variation and shows trends components. The forecasting model self adapts its parameters based on the forecasted errors observed via comparison with the actual performance at each reporting period. An iterative algorithm is used to adjust the forecasting parameters, thereby enhancing the convergence rate and the forecasting accuracy. An actual construction projects case study is presented to demonstrate the application of the proposed trending and forecasting method, the results show that this method is effective and improved forecasting accuracy over current methods.

Keywords: trending, forecasting, dynamic error reduction.

1. INTRODUCTION

Trending and forecasting are closely related management functions and sometimes used interchangeably, but there are distinct differences. Trending involves constructing models and analyzing those models against data with the intent to identify discernible patterns. Forecasting is the projection of these trends based on performance in conjunction with domain expertise to assess and understand their impact on a construction project. In a nut shell, first data is analyzed, trends are identified and performance is measured. Next, projections of those trends are used to forecast the total cost at completion. Finally, corrective action plans are proposed to mitigate the risk and ensure the integrity of the project.

2. LITERATURE REVIEW

The literature reveals that many models and methods have been developed for tracking and forecasting project status since the introduction of EVM in the mid- 1960s (e.g., Eldin and Hughes 1992; Alshibani, 1999; Moselhi et al 2004; Gabriel et al 2004; Moselhi and Hassanien, 2003; Nasira and Abd.Majid, 2006; Vandevoorde and Vanhoucke 2006; Kim 2007; Kim and Reinschmidt 2011; Moselhi 2011, Moselhi and Xiao 2011). Zwikael et al (2000) conducted a study to measure the performance of different models developed in forecasting project cost. They used a sample of actual projects and they concluded that the worst model in forecasting project cost is the one that is based on the assumption that the future performance will recover and the project will be completed within the original budget, while the models that incorporate both the SPI and the CPI were inferior to two models based on the CPI only.

Despite its wide acceptance and use, earned value based forecasting methods have received criticism by researchers, especially in forecasting project durations (e.g. Vandevoorde and Vanhoucke 2006; Moselhi 2011). Most criticism focused on three fundamental aspects: (1) schedule performance of a project is measured, analyzed, and predicted in units of value (e.g., money, labor, work quantity, and percent complete) instead of time unit (Kim and Reinschmidt 2011); (2) using schedule performance index (SPI) or schedule variance (SV)to forecast project duration can be misleading (Vandevoorde and Vanhoucke, 2006; Moselhi 2011); and (3) earned value method is a deterministic and provide point forecasts that does not provide information on the prediction bounds based on the likely accuracy of forecasts (Kim and Reinschmidt 2011). In an effort to overcome some limitations of using earned value for forecasting project performance, several models were developed (Vandevoorde and Vanhoucke, 2006; Moselhi, 2011). Vandevoorde and Vanhoucke (2006) compared three different methods to forecast project duration using earned value metrics and evaluated them on real-life project data. The authors concluded that the three methods produced a similar forecasting accuracy in the linear planned value case. However, introducing learning curves for the three methods may provide much more realistic forecasting accuracy. Moselhi 2011 introduced a new concept for the schedule performance index that measures the status of critical activities only and uses this index to forecast project durations.

This paper presents a newly developed method for forecasting project cost in an effort to provide a simple procedure that overcomes the some of the above mentioned limitations.

3. PROPOSED METHOD

3.1. Project Cost Trending

During the course of a project execution, cost deviations occur and differences between planned and actual values show up. The trend of these differences represents the momentum of change in the project cost. These changes may have either a positive or a negative impact to overall project cost. Cost variance trend analysis can provide early indication for a serious budget overrun or savings.

Moving Average (MA) is a tool commonly used in technical analysis of financial data, like stock prices, returns or trading volumes. The moving average is easy to calculate and, once plotted on a 2-D chart, becomes powerful visual trend spotting tool. The moving-average lines are used to easily identify the direction of the trend. When the stock value crosses below a moving average, it can be used as a simple trend changing signal. A move below the moving average (Figure 1) suggests that the stock value will likely move lower. Conversely, a cross above a moving average suggests that the stock value may be getting ready to make a move higher.

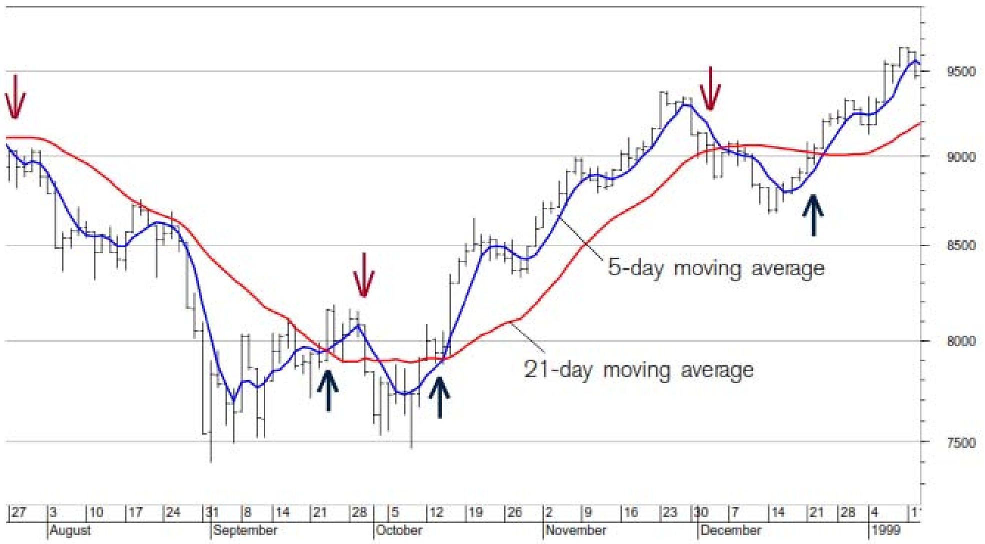

Figure 1: Moving Average lines

Two of the most common types of MA lines are the Simplified Moving Average (SMA) and the Exponential Moving Average (EMA).

The Simplified Moving Average (SMA) is a mean average constructed by summing up a set of cost variances over a specified period and dividing the summation by the period used. By its construction, SMA is seen as a lagging indicator since the SMA value will always be "behind" the cost variance.

$$SMA_n = \frac{\sum_{i=1}^{n} CV_i}{n} \quad (1)$$

Where,

n = number of periods in the moving average

CV_i = Actual Cost variance in period i

The Exponential Moving Average (EMA) is designed to reduce the lag in the SMA by applying more weight to the more recent cost variance data as compared to the older cost variance data.

$$EMA_i = (CV_i * \propto) + \left(EMA_{i-1} * (1{-}\propto)\right) \quad (2)$$

Where,

EMA_i = Current exponential moving average

EMA_{i-1} = Previous period exponential moving average

CV_i = Actual Current cost variance

α = Smoothing factor = $\frac{2}{n+1}$

n = Number of time periods

Moving averages are used to emphasize the direction of a trend and to smooth out fluctuations, or "noise", that can confuse interpretation. Typically, upward momentum is confirmed when a short-term average (e.g.9-weeks) crosses above a longer-term average (e.g. 20-weeks). Downward momentum is confirmed when a short-term average crosses below a long-term average.

3.2. Project Cost Trending Example

The trending method using the moving average is applied to a hydro project in Quebec, Canada. The project cost data are collected on a weekly basis. The project suffered from \$204,000 cost overrun. The weekly cost variance is plotted against the moving averages as shown in figure 2.

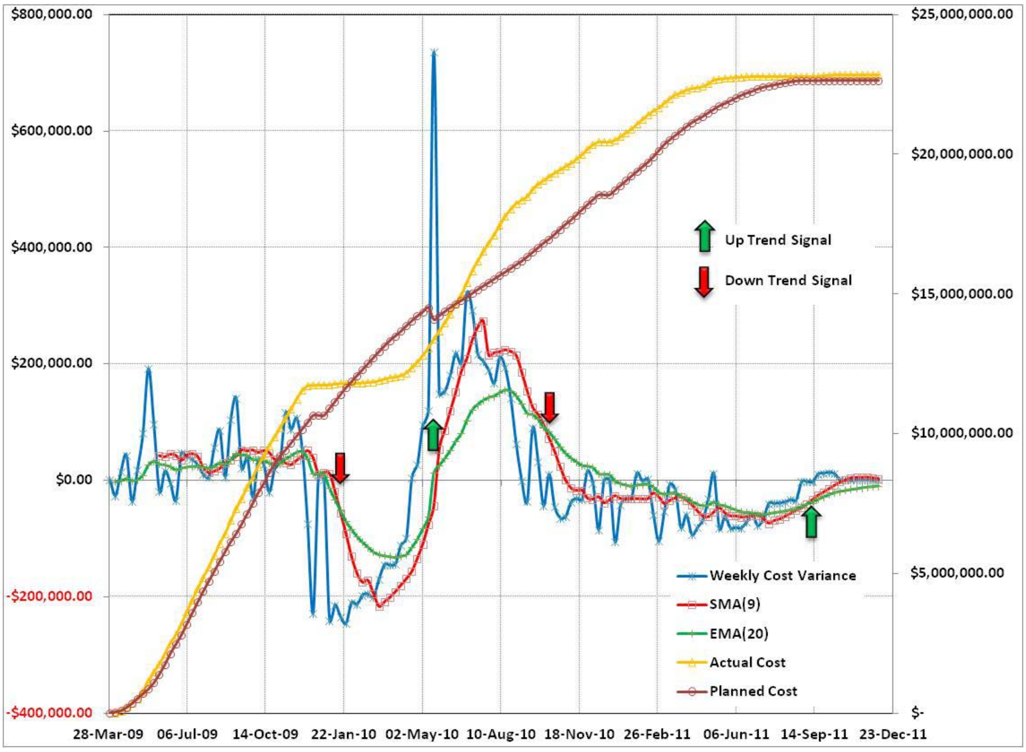

Figure 2: Case study Trend Analysis

The simple and exponential moving averages lines provide indications of the trend changing of the cost variance. Four trend changing points were spotted on figure 2. The first point was on Jan 10, 2010, the simple moving average SMA(9) crossed below the exponential moving average EMA(20), which indicated a downtrend in the project cost, and that was reflected on the actual project cost during the following periods. The second point was on May 23, 2010, the simple moving average SMA(9) crossed above the exponential moving average EMA(20) which indicated an uptrend in the project cost, and that was reflected with bigger gaps between the planned and the actual cost during the following periods. The third point was on Oct 10, 2010, the simple moving average SMA(9) crossed below the exponential moving average EMA(20), which indicated a downtrend in the project cost, and that was reflected with the gap between the planned and actual cost getting smaller. The fourth point was on Sept 04, 2011, the simple moving average SMA(9) crossed above the exponential moving average EMA(20) which indicated an uptrend in the project cost, and that was reflected with final project cost with a total cost overrun of $204,000. These signals give an early alert to the project manager in order to take the appropriate corrective actions.

3.3. Cost at Completion Forecasting

In order to develop an effective forecasting process, it is important to understand when and how to use the forecasting method, how to interpret the results and how to recognize the limitations and the potential for improvement. The self-adaptive method is used to forecast the total project cost from cost data collected during periodic project updates, while keeping improving the forecast through iteration. This method is based on the principles of iterated multi-step forecasting method. The proposed method forecasts the final cost of a project according to the following steps:

1. At time period t, the forecasting factor (δ_t) is calculated from the actual cost to date (AC_t), and the planned cost to date (PV_t),

$$\delta_t = \frac{AC_t}{PV_t} \tag{3}$$

2. Then, the project cost for the next period t+1 (FV_{t+1}) is forecasted using the previously calculated forecasting factor at time period t.

$$FV_{t+1} = \delta_t \times PV_{t+1} \tag{4}$$

3. At time period t+1, the forecasting factor (δ_{t+1}) is calculated,

$$\delta_{t+1} = \frac{AV_{t+1}}{PV_{t+1}} \tag{5}$$

4. The forecast error correction factor (ε_{t+1}) is calculated by dividing the actual cost to date (AV_{t+1}) by the forecast cost (FV_{t+1}),

$$\varepsilon_{t+1} = \frac{AV_{t+1}}{FV_{t+1}} \tag{6}$$

5. Then, the project cost for the next period t+2 (FV_{t+2}) is forecasted based on the forecasting factor and the forecast error correction factor,

$$FV_{t+2} = \frac{(\delta_{t+1} + \varepsilon_{t+1})}{2} \times PV_{t+2} \tag{7}$$

6. Then, the total project cost (EAC_t) is forecasted from the total project budget (BAC), the percentage cost variance and the forecasting correction factor,

$$EAC_t = BAC \times \frac{(\delta_{t+1} + \varepsilon_{t+1})}{2} \tag{8}$$

7. The above are repeated for the following time periods, which will enhance the forecasting accuracy through iteration. (Figure 3)

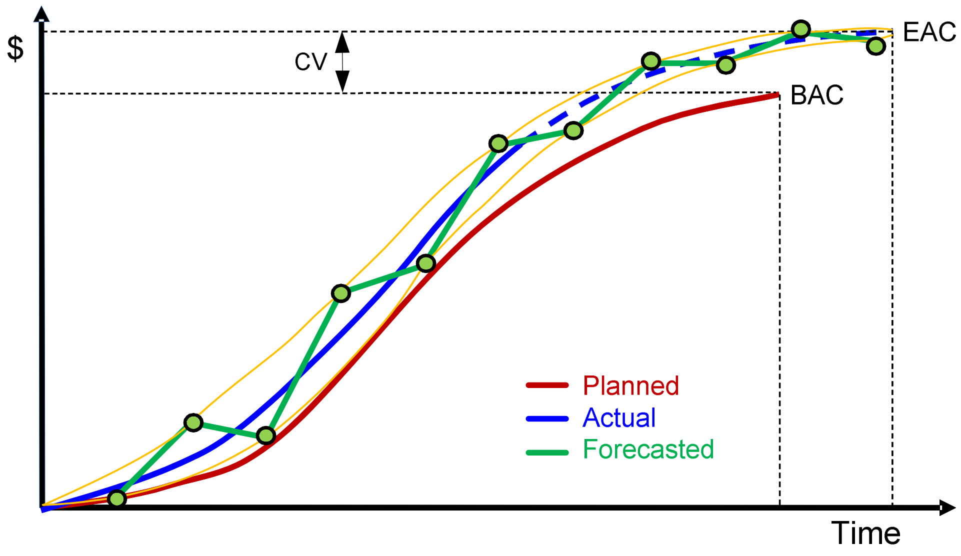

Figure 3: Self-Adaptive forecasting

4. ANALYSIS OF COST FORECASTING METHODS

There are number of criteria that can be used to evaluate a forecasting method: mean absolute error, accuracy, timeliness, and con- sistency. These concepts can be quantified as follows.

4.1. Mean Absolute Error

The mean absolute error (MAE) is a quantity used to measure how close forecasts or predictions are to the eventual outcomes. The mean absolute error is given by:

$$MAE = \frac{\sum_{i=1}^{m}|e_i|}{m} = \frac{\sum_{i=1}^{m}|Y_i - F_i|}{m} \quad (9)$$

Where: e_i = Absolute error at interval i

Y_i = Actual value at interval i

F_i = Forecasted value at interval i

m = number of intervals.

4.2. Mean Absolute Percentage Error

The mean absolute percentage error (MAPE), also known as mean absolute percentage deviation (MAPD), is a measure of accuracy of a method for constructing fitted time series values in statistics, specifically in trend estimation. It usually expresses accuracy as a percentage, and is defined by the formula:

$$MAPE = \frac{100\%}{m} \sum_{i=1}^{m} \left| \frac{Y_i - F_i}{F_i} \right| \tag{10}$$

Where: Y_i = Actual value at interval i

F_i = Forecasted value at interval i

m = number of intervals.

4.3. Mean Absolute Scaled Error

The mean absolute scaled error (MASE) is a measure of the accuracy of forecasts. It was proposed in 2006 by Australian statistician Rob J. Hyndman, who described it as:

$$MASE = \frac{1}{m} \sum_{i=1}^{m} \left(\frac{|e_i|}{\frac{1}{m-1} \sum_{i=2}^{m} |Y_i - Y_{i-1}|} \right) \tag{11}$$

Where: e_i = Absolute error at interval i

Y_i = Actual value at interval i

m = number of intervals.

5. EARNED VALUE METHOD VS PROPOSED METHOD

In this section, a comparison between the proposed method and the well known earned value method is performed. The comparison is based on the forecasting accuracy. Three different equations for the EVM estimation of the cost at completion EAC are used:

$$CPI = \frac{EV}{AC} \tag{12}$$

$$EAC_1 = \frac{BAC}{CPI} \tag{13}$$

$$EAC_2 = AC + BAC - EV \tag{14}$$

$$EAC_3 = AC + \frac{BAC - EV}{CPI} \tag{15}$$

Where,

EV is the earned value.

AC is the actual cost.

CPI is the cost performance index.

BAC is the budget at completion.

EAC_1, EAC_2, EAC_3 are the estimates at completion.

The application of the EVM and the proposed method are illustrated on a project of an airport luggage handling systems at Fabricom Airport Systems in Brussels (Belgium) (S. Vandevoordea and M. Vanhouckeb, 2006). The project was behind schedule but under cost. The data of the project is summarized in Table 1.

	Project	Category	Budget at completion	Cost at completion	Planed duration	Actual duration
1	Revamp check in	Under budget and behind schedule	€ 360,738	€ 349,379	9	13

Table 1: Luggage handling project at Fabricom Airport in Brussels (Belgium)

5.1. Forecast Results

Re-vamp check-in: The project concerns a revamping of different check-in islands. This project existed mainly out of electrical works (engineering, installation and commissioning) and automation works (programming, implementing and commissioning). The planned duration was 9 months, with a budget at completion of € 360.738. Table 2 presents the detailed project data. Figure 4 displays the different forecasting methods. The project was delivered 4 months later than expected, but under budget.

Date	Planned Value	Actual Cost	Earned Value	EAC1	EAC2	EAC3	Proposed method
Jun-02	28,975	25,567	25,645	28,887			
Jul-02	81,681	66,293	68,074	79,544	81,433	81,603	72,074
Aug-02	91,681	78,293	89,135	80,529	89,282	89,900	79,368
Sep-02	138,586	124,073	125,244	137,290	121,729	127,744	127,528
Oct-02	218,141	191,367	198,754	210,033	216,101	216,970	203,764
Nov-02	302,141	259,845	288,763	271,883	290,911	294,754	274,408
Dec-02	323,632	285,612	292,469	316,044	291,222	294,714	292,392
Jan-03	345,876	290,843	306,725	327,967	337,767	339,019	321,549

Feb-03	360,738	303,489	312,864	349,928	342,059	344,856	314,815
Mar-03	360,738	316,431	327,694	348,339	349,928	351,363	325,625
Apr-03	360,738	320,690	338,672	341,584	348,339	349,475	333,492
May-03	360,738	336,756	349,851	347,235	341,584	342,756	333,790
Jun-03	360,738	349,379	360,738	349,379	347,235	347,643	350,350

Table 2: Project detailed data

Table 3 shows the calculated mean absolute error, mean absolute percentage error and the mean absolute scaled error. The proposed method shows lower error than the forecasting using EVM.

Criteria	EAC1	EAC2	EAC3	Proposed Method
MAE	19,723.92	20,291.39	21,766.50	9,334.65
MAPE	7.91%	8.47%	8.99%	3.90%
MASE	0.73	0.75	0.81	0.35

Table 3: Project forecasting errors

The graph of the project cost along the project duration (Figure 4) reveals that the forecasted cost using the proposed method follows the actual cost with let deviation than the forecasted cost using EVM.

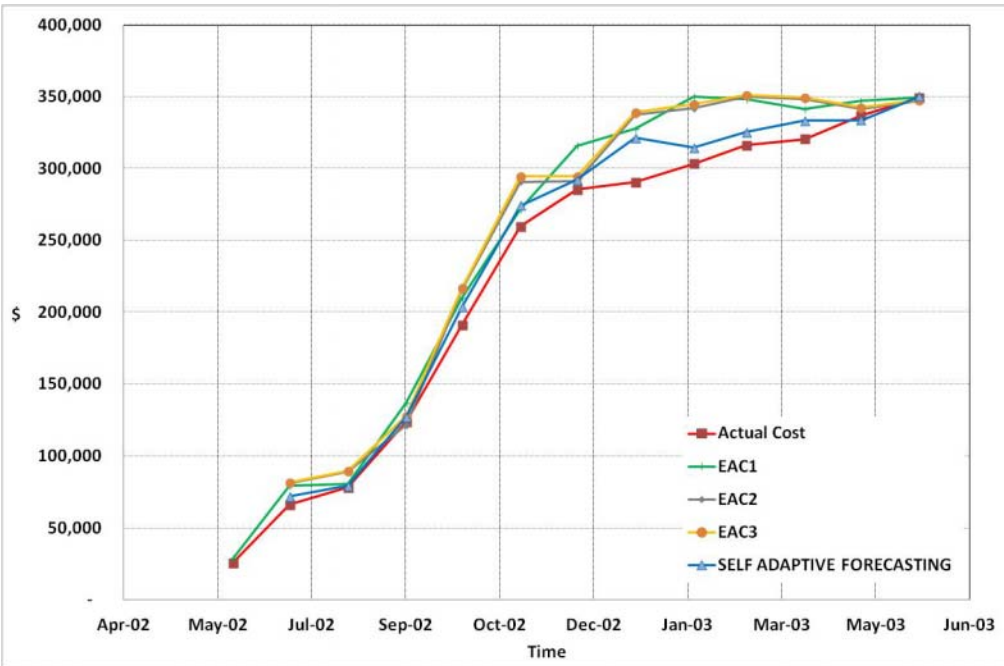

Figure 4: Project forecast

6. CONCLUSIONS

This paper presented a trending and forecasting method. The main characteristics of the proposed method are the following. First, it utilizes easily obtained cost data collected on regular basis such as to-date cost and to-date budget. Second, the method is simple enough to be integrated into any cost system. Third, the produced forecast is accurate, unbiased, stable and timely. The method was applied to a construction project; the results indicate that an automated forecast based on the algorithm developed in this paper can provide improved forecasts throughout the life of a project. The results show improved forecasting accuracy using the proposed method. It is important to recognize that no calculated forecast can hope to be very accurate given that the calculation has no knowledge of future project conditions.

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DEVELOPING PROPERTY SET/S IN THE IFC STANDARD FOR SUSTAINABLE CONSTRUCTION

Bahriye Ilhan
Istanbul Technical University, Istanbul, Turkey, ilhanba@itu.edu.tr

Hakan Yaman
Istanbul Technical University, Istanbul, Turkey, yamanhak@itu.edu.tr

Abstract

Building Information Modeling (BIM) as a growing movement in the architecture, engineering and construction (AEC) industry, is a new approach to manage building design and project data in digital format that provides the exchange and interoperability of information. On the other hand, the sustainability concept has been frequently encountered in the construction sector as in many other industries over the last two decades. Moreover, the adoption of technological innovations for sustainable data has been discussed in various studies. However, BIM integration with standards of sustainable construction is the main research problem. Therefore, it is intended to propose an Industry Foundation Classes (IFC)-based framework for providing an integrated platform to work on and facilitating the green documentation generation in order to get certification. The main purpose of the model is to provide a guideline for the design team to address the sustainable features of the project during the design stage. This paper focuses on the first step of the proposed model by designating the green properties to the BIM projects via developing Property Set/s, which are incorporated within the IFC structure. The research methodology includes the investigation of the major categories and criteria of the Green Building Assessment Systems, determination of the possible categories for IFC schema, creation of the Property Set/s and acquisition of the related data for green building documents. Due to the area of usage in Turkey, the model is discussed in terms of BREEAM scenario. Furthermore, the scope of the proposed property set/s is limited to the Materials category of BREEAM. Finally, the applicability to the other categories and even to the other assessment systems is discussed in conclusion.

Keywords: building information modeling, BIM, IFC, integration, sustainability.

1. INTRODUCTION

Building Information Modeling (BIM) has become one of the most important developments promising in the architecture, engineering and construction (AEC) industry by incorporating different tools and processes. It provides a three dimensional (3D) representation of a building that contains database storage mechanisms for properties and parameters of all the elements in that building unlike previous drawing methods, either manual or computer-aided (coordinate-based software, knowledge-based or object oriented systems) (Zyskowski and Valentine, 2009). The term BIM has been used in academia in various studies (Eastman, 1999; Eastman et al., 2011; Kymmell, 2008) and the value of BIM technology has been understood since the early 2000s in the construction industry and in academic studies related to construction. It has also been developed by computer-aided design (CAD) suppliers such as Autodesk, Bentley, Nemetschek and Graphisoft. Furthermore, it is widely acknowledged that BIM and Industry Foundation Classes (IFC) (buildingSMART, 2008) enable significant improvements of design processes and facilitate collaboration (Howard and Bjork, 2007; Kiviniemi et al., 2008).

On the other hand, the increasing attention to sustainability is pushing the construction industry towards rapid changes. Policies, laws and regulations around the world are asking the sector to adopt sustainable innovation in terms of products and processes to encourage more sustainable buildings (Hellstrom, 2007; Steurer and Hametner, 2011). Additionally, the studies show that the demand for sustainable building facilities with minimal environmental impact is increasing and sustainable buildings are considered as economically viable (Azhar, 2010; Azhar et al., 2011). Hence, the adoption of technological innovations for sustainable data has been discussed in the industry.

Since most sustainable decisions are made during the design stage of the building production process, integrating the sustainable data into this process via BIM is critically important. In the current situation, due to lack of measured sustainable strategies' direct access into BIM models, the integration requires considerable effort and time such that the evaluation of sustainable data remains an after design stage process for most of the cases. An integrated solution is an open research problem and can be addressed as the following sub-processes: (1) developing the property set/s in the IFC standard, (2) creating green materials database and library (3) generating BIM Model and IFC format (4) calculating the data for green documentation. This paper focuses on the first process of the proposed model for BIM integration with standards of sustainable construction. The main purpose of this study is determining the properties in the green building rating systems and proposing property set/s for IFC model schema.

2. BACKGROUND

Green BIM, as an emerging trend, has been increasingly discussed for more sustainable outcomes in various studies (for further details see: Azhar et al., 2011; Bank et al., 2010; Haagenrud et al., 2009; Krygiel and Nies, 2008; Lee et al., 2011; McGRAW_HILL Construction, 2010; Wu and Issa, 2011 and Zhao, 2011). An online survey designed by McGraw_Hill Construction for 2010 Green BIM Study is conducted with a range of industry professionals who use BIM tools to assess the level and scope of use of BIM tools to help achieve sustainability and/or building performance objectives as well as the expected level and scope of use in the future. The results of the study show that BIM is considered as an essential tool for green construction and expected in extensive use of green market in the near future. The report also makes a list of the areas that are key to the potential growth of Green BIM and its impact on the green building marketplace as follows: Software Integration, Integrated Output from Different Building Systems, Modeling Standards, Increasing Use of BIM for Small Green Retrofit Projects, Using BIM for Building Performance Monitoring and Verification and Greater Use of Integrated Design. On the other hand, studies regarding to relationship between BIM and Leadership in Energy and Environmental Design (LEED) have been carried out. For instance, Wu and Issa (2011) propose a 3rd party web service relying on BIM as the information backbone to facilitate the LEED documentation generation and management. Furthermore, the ways designers and planners may use BIM for various sustainability analyses in pursuit of LEED certification are presented (Azhar et al., 2011). Additionally, Bank et al. (2010) has worked on the integration of a decision-making framework for sustainable design of buildings with a BIM tool.

Even though the importance of using BIM technology for sustainability is discussed in the literature, there are some barriers to a fully integration such as lack of functional tools and complex structure of existing tools. This study aims to propose properties for IFC model schema to fill the gap of facilitating to get the green certification via BIM tools.

3. GREEN BUILDING RATING SYSTEMS

Green building rating systems are of great importance for dissemination of sustainable construction in the face of the increased demand for sustainability. Worldwide, there are more than 600 rating systems are available (BRE, 2008). These include but are not limited to: Australia's Green Star; Canada's LEED Canada; Germany's DGNB Certification System; India's IGBC Rating System and LEED India; Japan's Comprehensive Assessment System for Building Environmental Efficiency; New Zealand's Green Star NZ; South Africa's Green Star SA, United Kingdom's BRE Environmental Assessment Method (BREEAM) and the United State's LEED. Most of these rating systems' primary criteria are similar in that they evaluate a building's energy consumption, water efficiency, material use and indoor environmental quality (WorldGBC, 2010). This section gives a brief explanation of BREEAM and LEED due to their common usage in Turkey.

3.1. BRE Environmental Assessment Method (BREEAM)

BREEAM, the oldest assessment method developed by BRE in the United Kingdom as a tool to measure a building’s environmental performance, addresses wide-ranging sustainability issues and enables developers, designers and building managers to demonstrate the environmental credentials of their buildings to clients, planners and other initial parties (BREEAM, 2010).

While the original version of BREEAM was limited to the office buildings, it has been developed and is available in a range of building types including existing buildings. The main areas in the assessment system are Management, Health and Well-Being, Energy, Transport, Water, Materials, Waste, Land Use and Ecology, Pollution and Innovation (added in 2009 version) respectively. Credits are awarded in each area according to performance and then added together through a combined weighting process in order to rate the building on a scale of Pass, Good, Very Good, Excellent or Outstanding and finally a certificate is awarded to the project (Krygiel and Nies, 2008). Furthermore, BREEAM International, BREEAM Europe Commercial and BREEAM Gulf are the other categories developed for using aside from the UK.

3.2. Leadership in Energy and Environmental Design (LEED)

LEED was developed by USGBC in 1998 for the purpose of sustainable buildings via measurement standards (USGBC, 2011). LEED system, initially introduced for new construction (NC), has been developed over time in various versions for different types of buildings such as LEED for Core and Shell Development (CS), Commercial Interiors (CI), Existing Buildings (EB), Homes (H), Schools (S), and Retail (R). Under the LEED-NC system, buildings are judged via a credit system in five categories of environmental performance and one additional area for innovative strategies, which are Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Innovation and Design (Krygiel and Nies, 2008). The final score is obtained by adding the credits from each category to determine the level of certification awarded to the project. The LEED levels of certification are Certified, Silver, Gold and Platinum based on the points.

4. INDUSTRY FOUNDATION CLASSES (IFC)

IFC provides a neutral data format, which is an ISO global standard and enabling interoperability between systems (Liebich et al., 2006). It represents BIM for sharing construction and facility management data across various applications used in the Architecture, Engineering, Construction and Facility Management (AEC-FM) industry (Howard and Björk, 2007). IFCs include object specifications or classes and provide a useful structure for data sharing among applications (Vanlande et al., 2008).

Due to its advantages and flexibility for exchanging the data between different types of software used in the AEC industry, IFC-based framework is intended for the proposed model.

5. PROPERTY SETS FOR INTEGRATED BIM – SUSTAINABLE DATA MODEL

In this section, the first step of integrated BIM – sustainable data model is discussed. To effectively determine the property set/s, the process includes three main steps, which are examining the green building assessment system, the analysis of the major category areas of that assessment system and determining the property set/s for IFC model schema respectively (Figure 1).

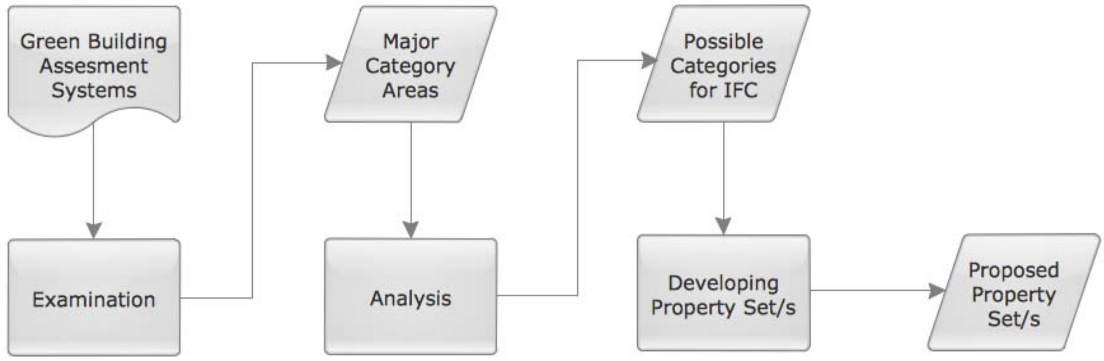

Figure 1: Property Set Determination Process

5.1. BREEAM Scenario

Due to the area of usage in Turkey and lack of BREEAM – BIM studies in the literature; the model is addressed in terms of BREEAM. In this sense, BREEAM Europe Commercial 2009 Assessor Manual is examined.

Each category for certification process is intended to be a property set with the criteria as their properties. The proposed psets are listed as Pset_BRManagement, Pset_BR HealthandWellBeing, Pset_BREnergy, Pset_BRTransport, Pset_BRWater, Pset_BRMaterials, Pset_BRWaste, Pset_BRLandUseandEcology, Pset_BRPollution, Pset_BRInnovation.

5.2. Proposed Property Set/s

The scope of the proposed property set/s is limited to the Materials category of BREEAM Europe Commercial 2009 as illustrated in Figure 2. The property set is generated for schema IfcArchitectureDomain in the domain layer of the general IFC architecture and applicable to IfcProject entity.

IFC2*x3* Property Set Definition Reference

PropertySet Definition:

PropertySet Name	Pset_BRMaterials
Applicable Entities	IfcProject
Applicable Type Value	
Definition	Material properties for BREEAM Certification

Property Definitions:

Name	Property Type	Data Type	Definition
Mat 1_Materials Specification (Major Building Elements)	IfcPropertySingleValue	IfcBoolean	Identifies if the construction materials are Green Guide to Specification (= TRUE) or Other Materials Assessment Tools (= FALSE)
Mat 2_Hard Landscaping and Boundary Protection	IfcPropertySingleValue	IfcBoolean	Identifies if there is a natural boundary protection (= TRUE) or not (= FALSE) and the materials for boundary protection and external hard surfaces are Green Guide to Specification (= TRUE) or Other Materials Assessment Tools (= FALSE)
Mat 3_ Re-Use of Facade	IfcPropertySingleValue	IfcBoolean	Identifies if existing building facades are in-situ reused (= TRUE) or not (= FALSE)
Mat 4_ Re-Use of Structure	IfcPropertySingleValue	IfcBoolean	Identifies if existing structures that previously occupied the site are reused (= TRUE) or not (= FALSE)
Mat 5_ Responsible Sourcing of Materials	IfcPropertySingleValue	IfcBoolean	Identifies if sourced materials are used for key (main) building elements (= TRUE) or not (= FALSE)
Mat 6_Insulation	IfcPropertySingleValue	IfcBoolean	Identifies if the thermal insulation is Green Guide to Specification and has been responsibly sourced (= TRUE) or not (= FALSE)
Mat 7_ Designing for Robustness	IfcPropertySingleValue	IfcBoolean	Identifies if there are adequate protection of exposed parts of the building and landscape (= TRUE) or not (= FALSE)

Figure 2: The Proposed Pset_BRMaterials (Pset_BRMaterials.xml)

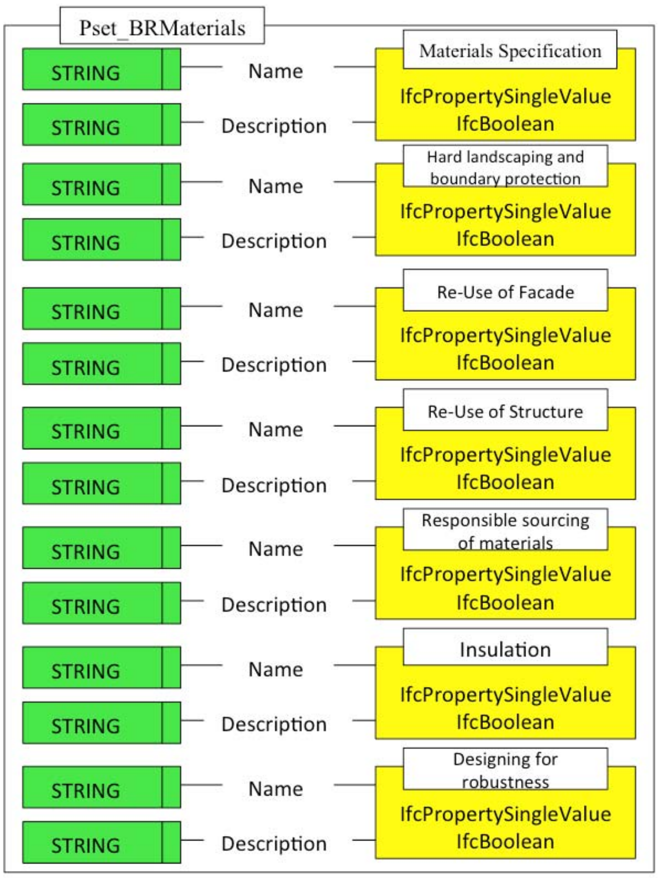

Figure 3: Pset_BRMaterials Schema

Due to the required specific calculations for each property, all data types are set as IfcBoolean. The definitions, therefore, are addressed in the question form. According to the answers of the properties, further calculations will be made based on the BREEAM assessment for each criteria.

Figure 3 presents the property set in the IFC schema form while Figure 4 provides the EXPRESS-G schema in the new IFC release – IFC4 for BREEAM. The other Pset/s can be approached similarly.

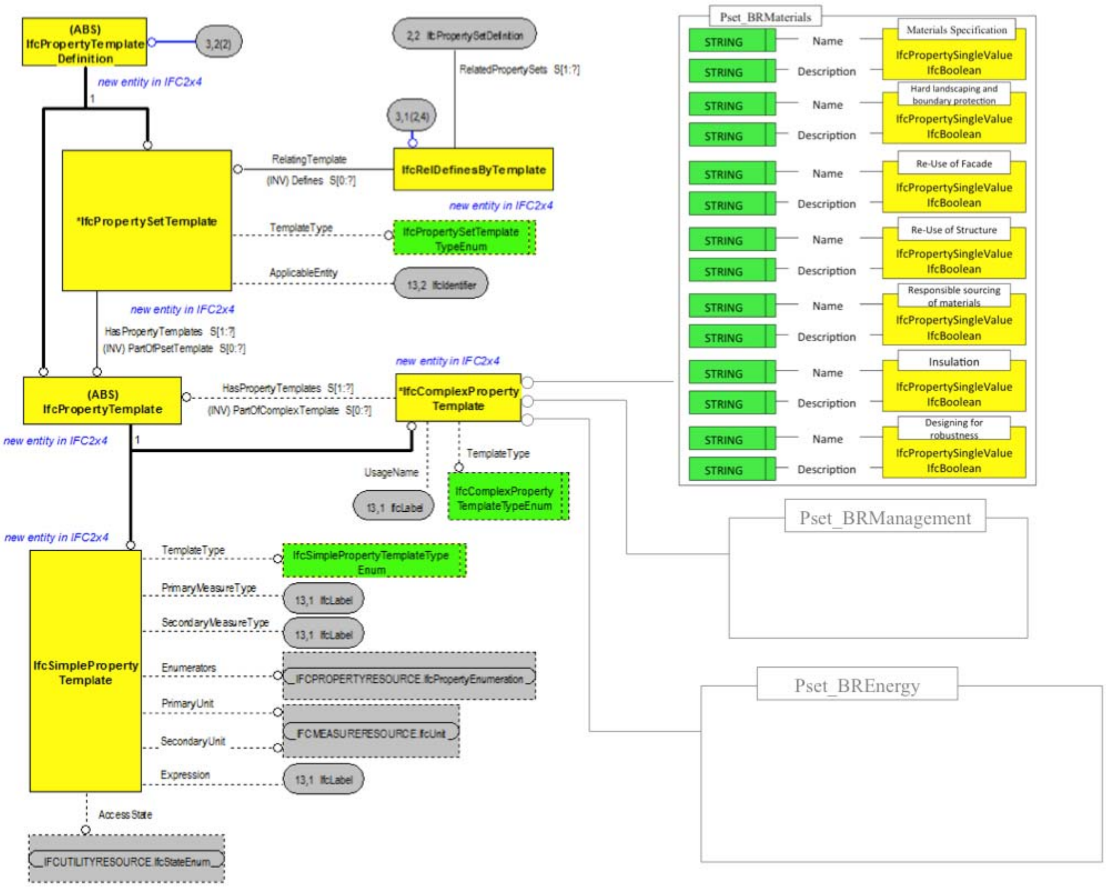

Figure 4: The Schema for BREEAM (IFC4)

6. CONCLUSIONS

Since BIM provides an opportunity for superposing the multidisciplinary information within one model powerfully, the importance of sustainable data addition into the BIM model has been discussed recently due to the increased demand for green certification. In this sense, integrated design process with sustainable properties simplifies the certification process in terms of time and cost.

In this study, a supporting method that facilitates the sustainable project decisions generated by BIM software is proposed by determining properties based on BREEAM and developing them as pset/s for IFC model schema as the first step of an integrated BIM – Sustainable Data model which is an on-going PhD study. The examination of other categories of BREEAM and their development in the IFC standard can be considered as future studies. Furthermore, a case study will be conducted for validating the proposed integrated model including the calculations for each criteria and possible credits as the output data.

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A MIXED-INTEGER LINEAR MODEL FOR OPTIMIZATION OF RESOURCE IDLE DAYS IN PROJECT SCHEDULING

Mahdi Abbasi Iranagh
Middle East Technical University, Ankara, Turkey, mahdi.iranagh@metu.edu.tr

Tankut Atan
Isik University, Istanbul, Turkey, tatan@isikun.edu.tr

Rifat Sonmez
Middle East Technical University, Ankara, Turkey, rsonmez@metu.edu.tr

Abstract

In scheduling of construction projects, the pattern of resource demand over time is very important for effective allocation of resources. However critical path method (CPM) only considers the precedence relations between the activities during scheduling. Hence, the resource diagram obtained by CPM should be leveled for optimal allocation of resources. The main objective of resource leveling problem (RLP) is to minimize the fluctuations in the resource diagram by shifting the non-critical activities through their floats. Resource leveling is crucial for effective use of construction resources, particularly manpower and machinery resources, to minimize project costs.

Mixed-integer linear programming method is commonly used to determine an exact solution for the RLP. Previous integer-linear models included sum of squares of daily resource requirements, and the absolute deviation between the resource requirement and a uniform resource level as the resource leveling metrics to measure and minimize the resource fluctuations. In recent years, Resource Idle Days (RID) together with Maximum Resource Demand (MRD) was proposed as an alternative resource leveling metric to achieve a metric to maximize the efficiency of resource utilization in construction projects.

This study presents a mixed-integer model for the RLP in which RID-MRD is used as the resource leveling metric. The model is integrated into MS Excel and GAMS/CPLEX software in order to have a simplified application. The performance of the application is tested for leveling problems including up to 30 activities and four resources.

Keywords: mixed integer linear programming, optimization, project management, resource leveling, scheduling.

1. INTRODUCTION

Effective planning of resources is crucial to remain competitive in today's highly competitive business environment (Hegazy 1999). Critical path method (CPM), which is commonly used for scheduling of construction projects, often causes some undesirable fluctuations in resource demand profile. These fluctuations are costly to implement in projects because they require keeping some workers idle during low demand periods, or hiring and releasing the workers in short periods. This can lead to difficulties in attracting and keeping high performance work teams and make disruption in the learning curve (El-Rayes and Jun 2009; Harris 1978; Stevens 1990). The fluctuations in the resource diagram can be minimized by shifting the non-critical activities through their floats. Hence the main objective of resource leveling problem (RLP) is to obtain an efficient resource allocation for the project.

Resource leveling problem (RLP) is NP-hard in the strong sense (Neumann et al. 2003), and exact methods may require significant amount of computational time especially for large projects. However, numerous research have focused on exact methods for solving RLP, since they provide a benchmark to measure and compare the performance of heuristics or meta-heuristics. As one of the early contributions, Easa (1989) developed an integer-linear programing model to minimize the sum of absolute deviations of resource demand from average resource utilization. Bandelloni et al. (1994) presented a non-serial dynamic programming model to minimize the squared deviations of resource demand from average resource consumption. Mattila and Abraham (1998) suggested an integer-linear programing model to minimize the sum of absolute deviations of resources from average resource use, in a highway construction scheduled by linear scheduling method. Son and Mattila (2004) suggested a linear programing model to minimize the sum of absolute deviations of resources from average resource use via activity splitting. Majority these studies include small example problems with single resources, and do not provide any computational performance analysis. Neumann and Zimmermann (2000) proposed a branch-and-bound based model to minimize the sum of squared resource utilization by general temporal scheduling method. The procedure was successfully applied to solve problems up to 20 activities with five resources. Gather et al. (2010) proposed a branch-and-bound algorithm to minimize the sum of squared resource utilization. Gather et al. (2010) was able to solve a large number of instances up to 20 activities to optimality. In a recent study, Rieck et al. (2012) developed a mixed-integer linear programing model considering both sum of squared resource utilization and sum of positive deviations of daily resource demand from average resource demand. Rieck et al. (2012) solved instances up to 50 activities and five resources to optimality.

Previous linear models presented in the literature included sum of squares of daily resource demands and deviations of resource demand from average resource demand as leveling metrics. In recent years, El-Rayes and Jun (2009) presented two new resource leveling metrics: (1) Release and re-hire (RRH); total amount of resources that need to be temporarily released and rehired during the entire project duration and (2) Resource idle days (RID); total number of idle and nonproductive resource days during the entire project duration. El-Rayes and Jun (2009) has shown that the new metrics are capable of outperforming existing metrics in eliminating undesirable resource fluctuations and resource idle time. However although RID is capable of directly measuring and minimizing the negative impact of resource fluctuations on construction productivity it has very limited capabilities to minimize the peak resource demand. Hence, El-Rayes and Jun (2009) suggested using RID and maximum resource demand (MRD) jointly to overcome this shortcoming. The combined metric RID-MRD minimizes the resource fluctuations and peak resource simultaneously. Despite the fact that RID-MRD enables a metric of practical significance the literature does not include a linear model for this metric.

This research presents a mixed-integer model in which RID-MRD is included as the objective function. In order to have a simplified application, the model is integrated into MS Excel and GAMS/CPLEX software. Problem instances up to 30 activities and four resources are selected from literature to evaluate the performance of the model.

2. MODEL DESCRIPTION

In this section the mixed-integer model for the RID-MRD is described along with the MS Excel and GAMS/CPLEX application.

2.1. Model inputs

We considered the projects in which $I = \{1, 2, \dots, I\}$ is the set of activities where $i = 1$ is the start activity and $i = \mathrm{I}$ is the finish activity of the project. Set $T = \{0, 1, \dots, T\}$ represents the times (days) within the project duration that, $t = 0$ stands for the start day and $t = T$ refers to the last or finishing day of the project. Similarly, $R = \{1, 2, \dots, R\}$ defines the set of resources, and finally, $N = \{0, 1, \dots, N\}$ denotes the set of total daily demand for each resource by the activities.

Parameters of the model are as follows: EST_i and LST_i represent the early start, and late start times of i^{th} activity; d_i is the duration of i^{th} activity; $r_{i,r}$ is the demand for resource r by i^{th} activity; w_r is the weight of resource r; D is the total project duration; and $p_{i,j}$ is the relationship between activities i and j where:

$$p_{i,j} : \begin{cases} 1 & \text{if activity } j \text{ should be finished before activity } i; \\ 0 & o/w. \end{cases}$$

The following variables are then defined for the model. z_1 is the weighted sum of maximum daily resource demand of all resources and, z_2 is the the weighted sum of resource idle days of all resources; f_i is the start day of i^{th} activity; $u_{t,r}$ is the daily demand of resource r at day t; mxu_r is the maximum daily demand of the resource r; $mx1u_{t,r}$ is the maximum daily demand for resource r before day t; and, $mx2u_{t,r}$ is the maximum daily demand for resource r after day t; ; $mnu_{t,r}$ is the smallest of of $mx1u_{t,r}$ or $mx2u_{t,r}$ for each day and for each resource. Finally variables $\lambda_{n,t,r}$, $\varphi_{t,i}$ and $\sigma_{t,i}$ are defined as follows:

$$\lambda_{n,t,r} : \begin{cases} 1 & \text{if demand for resource } r \text{ at time (day) } t \text{ is equal to } n; \\ 0 & o/w. \end{cases}$$

$$\varphi_{t,i} : \begin{cases} 1 & \text{if activity } i \text{ is under progress at time (day) } t; \\ 0 & o/w. \end{cases}$$

$$\sigma_{t,i} : \begin{cases} 1 & \text{if activity } i \text{ has started at time (day) } t; \\ 0 & o/w. \end{cases}$$

2.2. Models

Mathematical formulation of the objective function for RID, MRD and RID-MRD is shown in equations (1), (2) and (3):

$$\text{RID} = \sum_t \sum_r w_r(min\ (max(u_{1,r}, \dots, u_{t,r}), max(u_{t,r}, \dots, u_{T,r})) - u_{t,r}) \tag{1}$$

$$\text{MRD} = \sum_r w_r max\ (u_{1,r}, \dots, u_{T,r}) \tag{2}$$

$$\text{RID/MRD} = W_{RID} RID + W_{MRD} MRD \tag{3}$$

where; W_{RID} is the planner defined weight for RID, and W_{MRD} is the planner defined weight for MRD. Since above mentioned functions are not linear, they are modeled as linear functions. Variable z_1 in Eq. (4) represents RID objective function and equations (5) to (9) describe related constraints.

$$\min\ z_1 = \sum_t \sum_r w_r (mnu_{t,r} - u_{t,r}) \tag{4}$$

Constraints:

$$u_{t',r} \leq mx1u_{t,r}\ \forall t' \leq t, \qquad \forall t \in T, \forall r \in R \tag{5}$$

$$u_{t',r} \leq mx2u_{t,r}\ \forall t' \geq t, \qquad \forall t \in T, \forall r \in R \tag{6}$$

$$mnu_{t,r} \leq mx1u_{t,r} \qquad \forall t \in T, \forall r \in R \tag{7}$$

$$mnu_{t,r} \leq mx2u_{t,r} \qquad \forall t \in T, \forall r \in R \tag{8}$$

$$mx1u_{t,r}, mx2u_{t,r}, mnu_{t,r} \in \aleph_0 \qquad \forall t \in T, \forall r \in R \tag{9}$$

Eq. (4) minimizes the weighted sum of the differences between the resource demand for each day and the smallest of maximum resource demand before and after that day,. The variables $mx1u_{t,r}$ and $mx2u_{t,r}$ are the maximum resource demand before and after the

t^{th}day. Equations (5) and (6) ensure the daily resource demands before and after day t are not greater than the values $mx1u_{t,r}$ and $mx2u_{t,r}$. Eq. (7) and Eq. (8) select the smaller value between $mx1u_{t,r}$ and $mx2u_{t,r}$. Eq. (9) says that $mx1u_{t,r}, mx2u_{t,r}$ and $mnu_{t,r}$ are non-negative integers.

Variable z_2 in Eq. (10) corresponds to MRD objective function and Eq. (10) minimizes the total weighted maximum daily demand for each resource.

$$\min\ z_2 = \sum_r w_r mxu_r \tag{10}$$

Constraints:

$$u_{t,r} \le mxu_r \quad \forall t \in T, \forall r \in R \tag{11}$$

$$mxu_r \in Z_0 \qquad \forall r \in R \tag{12}$$

Variable mxu_r is the maximum daily demand for resource r. The maximum daily resource demand of each resource is expressed as a variable. The daily resource demand for a resource can not be larger than the maximum daily demand (Eq. 11). Variable mxu_r is a non-negative integer (Eq. 12). Equations (13) to (26) are the other constraints in the model.

$$\sum_i r_{i,r}\varphi_{t,i} = u_{t,r} \quad \forall t \in T, \quad \forall r \in R \tag{13}$$

$$p_{i,j}f_i \ge p_{i,j}(f_j + d_j) \quad \forall i,j \in I, \quad i \ne j \tag{14}$$

$$\sum_{EST_i \le t \le LST_i} t\sigma_{t,i} = f_i \quad \forall i \in I \tag{15}$$

$$\sum_{EST_i \le t \le LST_i} \sigma_{t,i} = 1 \quad \forall i \in I \tag{16}$$

$$\varphi_{t,i} = \sum_{t=\max(EST_i, t-d_i+1)}^{\min(LST_i, t)} \sigma_{t,i} \quad \forall t \in T, \quad \forall i \in I, \quad EST_i \le t \le LST_i + d_i - 1 \tag{17}$$

$$\varphi_{t,i} = 0 \quad \forall t \in T, \quad \forall i \in I, \quad t < EST_i \tag{18}$$

$$\varphi_{t,i} = 0 \quad \forall t \in T, \quad \forall i \in I, \quad t > LST_i + d_i - 1 \tag{19}$$

$$f_1 = 0 \tag{20}$$

$$f_I \le D \tag{21}$$

$$\sigma_{0,1} = 1 \tag{22}$$

$$u_{t,r} \in \aleph_o \quad \forall t \in T, \quad \forall r \in R \tag{23}$$

$$f_i \in Z_o \quad \forall i \in I \tag{24}$$

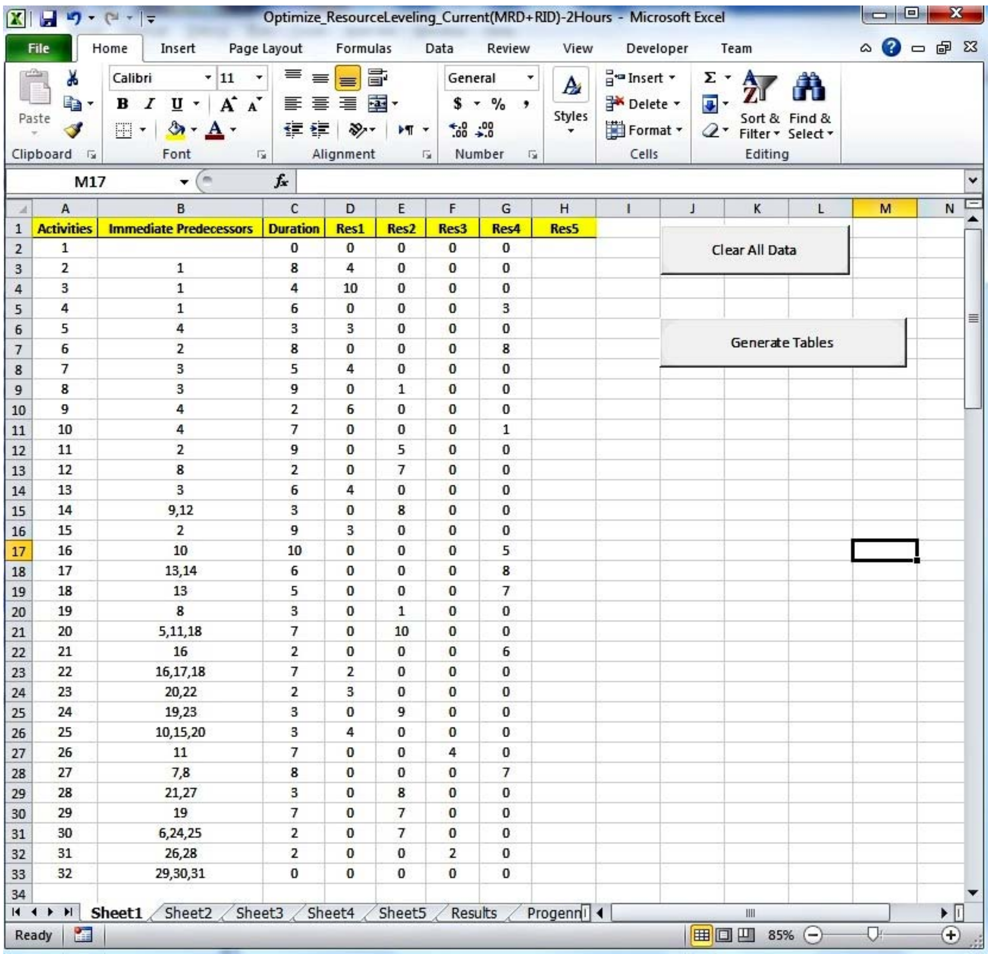
$$\varphi_{t,i} \in \{0,1\} \quad \forall t \in T, \quad \forall i \in I \tag{25}$$

$$\sigma_{t,i} \in \{0,1\} \quad \forall t \in T, \quad \forall i \in I \tag{26}$$

Eq. (13) defines the daily resource demand for resource type r and ensures that the activities use the resources only in days when they are active. Eq. (14) ensures the precedence relationships between the activities are satisfied. Eq. (15) determines activity start day. Eq. (16) ensures that activities can start only in a day between their early start and late start times. Eq. (17) determines the days that activities are active and ensures that the days that activities are active are consecutive. Equations (18) and (19) ensure that the activities are active only between early start and late finish days. First and last activities are dummy activities that identify the start and finish dates of the project. Equations (20) and (22) ensure that the first activity starts at day 0, and Eq. (21) ensures that all activities are completed before the dummy finish activity. Variables $u_{t,r}$ and f_i are non-negative integers, and $\varphi_{t,i}$ and $\sigma_{t,i}$ are binary variables.

3. MS EXCEL AND GAMS/CPLEX APPLICATION

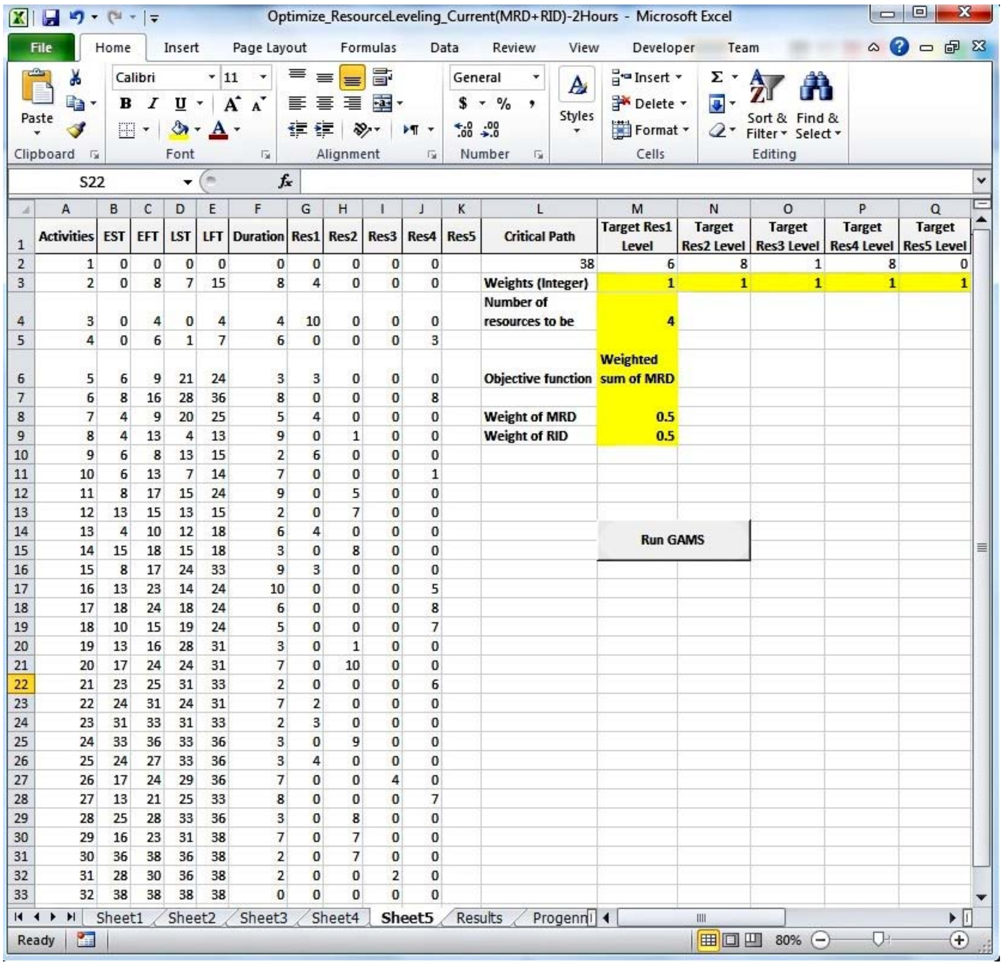
A MS Excel template is used to define the proposed mixed-integer linear programing model and to carry out input/output operations with the GAMS/CPLEX solver. The optimization process then is done by the GAMS/CPLEX solver. In Fig. 1, the Excel template used to input the problem data is shown.



Activities	Immediate Predecessors	Duration	Res1	Res2	Res3	Res4	Res5
1		0	0	0	0	0	
2	1	8	4	0	0	0	
3	1	4	10	0	0	0	
4	1	6	0	0	0	3	
5	4	3	3	0	0	0	
6	2	8	0	0	0	8	
7	3	5	4	0	0	0	
8	3	9	0	1	0	0	
9	4	2	6	0	0	0	
10	4	7	0	0	0	1	
11	2	9	0	5	0	0	
12	8	2	0	7	0	0	
13	3	6	4	0	0	0	
14	9,12	3	0	8	0	0	
15	2	9	3	0	0	0	
16	10	10	0	0	0	5	
17	13,14	6	0	0	0	8	
18	13	5	0	0	0	7	
19	8	3	0	1	0	0	
20	5,11,18	7	0	10	0	0	
21	16	2	0	0	0	6	
22	16,17,18	7	2	0	0	0	
23	20,22	2	3	0	0	0	
24	19,23	3	0	9	0	0	
25	10,15,20	3	4	0	0	0	
26	11	7	0	0	4	0	
27	7,8	8	0	0	0	7	
28	21,27	3	0	8	0	0	
29	19	7	0	7	0	0	
30	6,24,25	2	0	7	0	0	
31	26,28	2	0	0	2	0	
32	29,30,31	0	0	0	0	0	

Figure 1: Problem inputs sheet

Once the activities' predecessors, durations and resources' demands are inputted, "Generate Tables" button is selected to carry out the CPM calculations. Weights of resources (w_r) and weights of objectives (W_{RID} and W_{MRD}) are defined in the MS Excel sheet shown in Fig. 2.



Activities	EST	EFT	LST	LFT	Duration	Res1	Res2	Res3	Res4	Res5	Critical Path	Target Res1 Level	Target Res2 Level	Target Res3 Level	Target Res4 Level	Target Res5 Level
1	0	0	0	0	0	0	0	0	0		38	6	8	1	8	0
2	0	8	7	15	8	4	0	0	0		Weights (Integer)	1	1	1	1	1
3	0	4	0	4	4	10	0	0	0		Number of resources to be	4				
4	0	6	1	7	6	0	0	0	3							
5	6	9	21	24	3	3	0	0	0		Objective function	Weighted sum of MRD				
6	8	16	28	36	8	0	0	0	8							
7	4	9	20	25	5	4	0	0	0		Weight of MRD	0.5				
8	4	13	4	13	9	0	1	0	0		Weight of RID	0.5				
9	6	8	13	15	2	6	0	0	0							
10	6	13	7	14	7	0	0	0	1							
11	8	17	15	24	9	0	5	0	0							
12	13	15	13	15	2	0	7	0	0							
13	4	10	12	18	6	4	0	0	0							
14	15	18	15	18	3	0	8	0	0							
15	8	17	24	33	9	3	0	0	0							
16	13	23	14	24	10	0	0	0	5							
17	18	24	18	24	6	0	0	0	8							
18	10	15	19	24	5	0	0	0	7							
19	13	16	28	31	3	0	1	0	0							
20	17	24	24	31	7	0	10	0	0							
21	23	25	31	33	2	0	0	0	6							
22	24	31	24	31	7	2	0	0	0							
23	31	33	31	33	2	3	0	0	0							
24	33	36	33	36	3	0	9	0	0							
25	24	27	33	36	3	4	0	0	0							
26	17	24	29	36	7	0	0	4	0							
27	13	21	25	33	8	0	0	0	7							
28	25	28	33	36	3	0	8	0	0							
29	16	23	31	38	7	0	7	0	0							
30	36	38	36	38	2	0	7	0	0							
31	28	30	36	38	2	0	0	2	0							
32	38	38	38	38	0	0	0	0	0							

Figure 2: Model inputs sheet

"Run GAMS" button is used to create the integer linear model and to transfer the model information to the GAMS/CPLEX solver (Fig. 2).

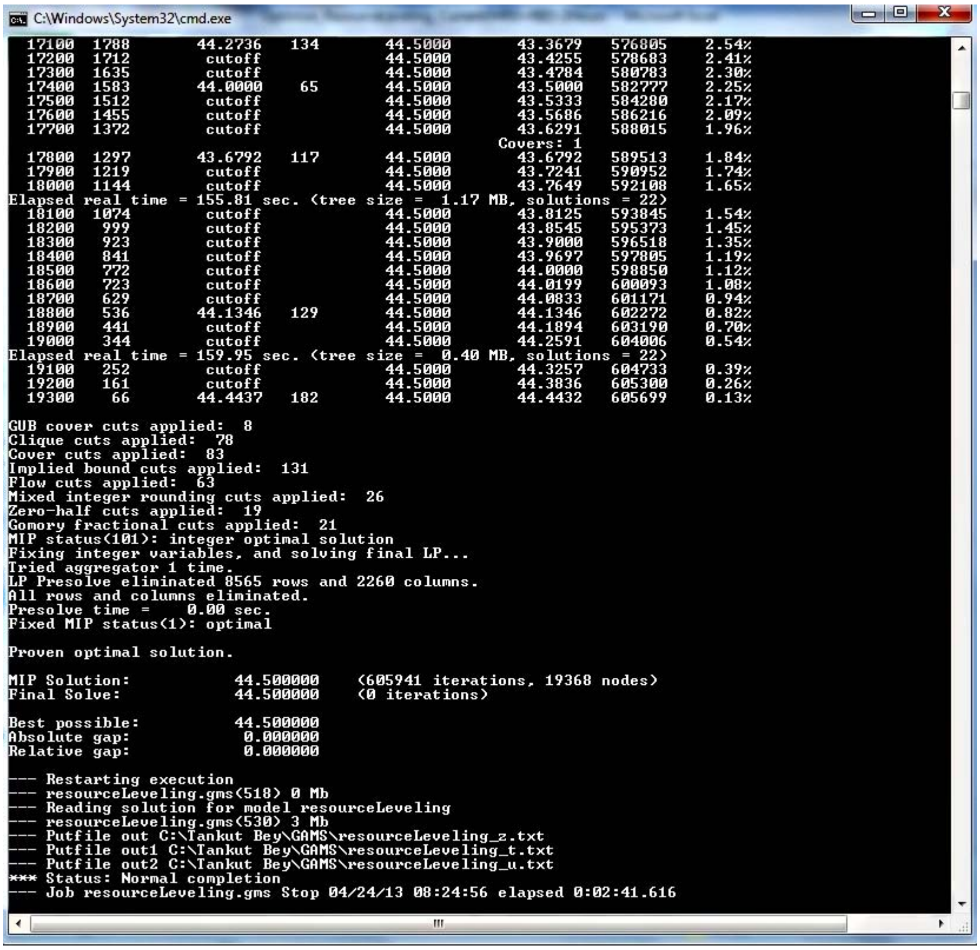
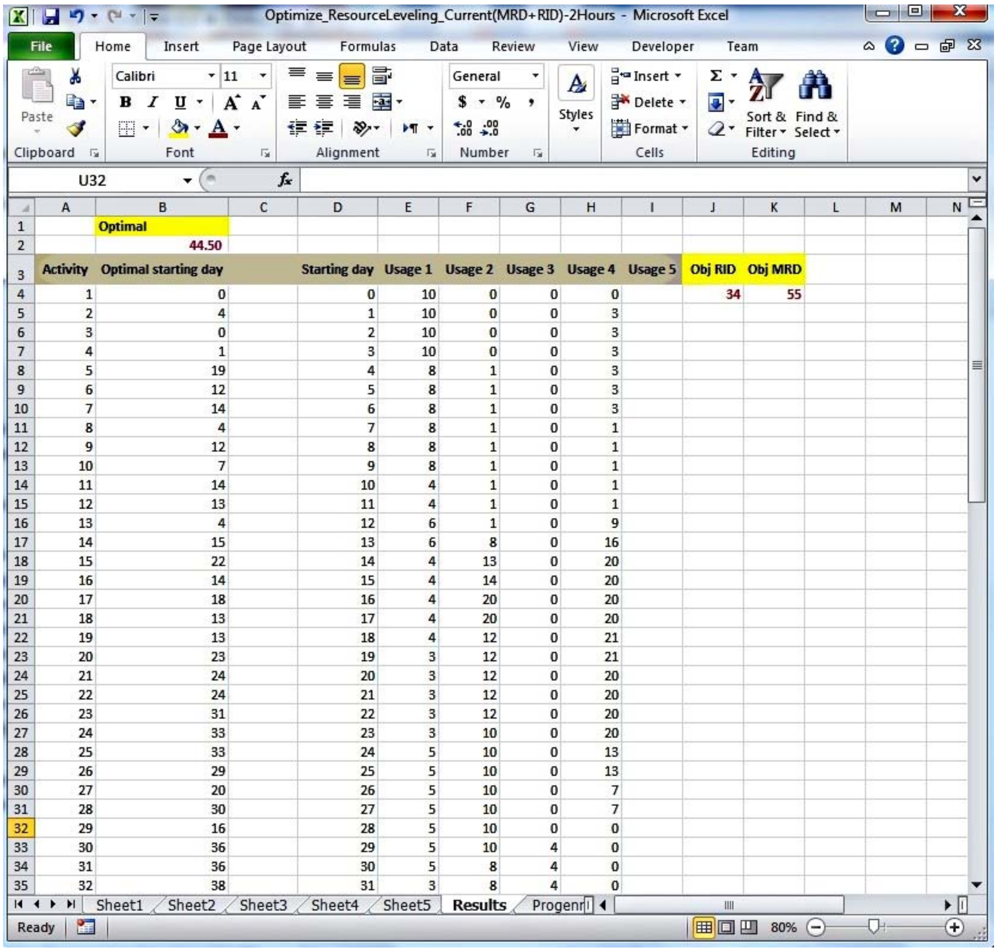


Figure 3: GAMS results

Finally, when GAMS solver achieves an optimal solution as shown in Fig. 3, the results are transfered to the MS Excel sheet (Fig. 4). In the result sheet (Fig. 4), cell B-2 cell displays the value of total weighted RID-MRD objective function (Eq. 3). Column B gives the start days of activities for the optimal solution (Fig. 4).



Optimal
44.50

Activity	Optimal starting day	Starting day	Usage 1	Usage 2	Usage 3	Usage 4	Usage 5	Obj RID	Obj MRD
1	0	0	10	0	0	0		34	55
2	4	1	10	0	0	3			
3	0	2	10	0	0	3			
4	1	3	10	0	0	3			
5	19	4	8	1	0	3			
6	12	5	8	1	0	3			
7	14	6	8	1	0	3			
8	4	7	8	1	0	1			
9	12	8	8	1	0	1			
10	7	9	8	1	0	1			
11	14	10	4	1	0	1			
12	13	11	4	1	0	1			
13	4	12	6	1	0	9			
14	15	13	6	8	0	16			
15	22	14	4	13	0	20			
16	14	15	4	14	0	20			
17	18	16	4	20	0	20			
18	13	17	4	20	0	20			
19	13	18	4	12	0	21			
20	23	19	3	12	0	21			
21	24	20	3	12	0	20			
22	24	21	3	12	0	20			
23	31	22	3	12	0	20			
24	33	23	3	10	0	20			
25	33	24	5	10	0	13			
26	29	25	5	10	0	13			
27	20	26	5	10	0	7			
28	30	27	5	10	0	7			
29	16	28	5	10	0	0			
30	36	29	5	10	4	0			
31	36	30	5	8	4	0			
32	38	31	3	8	4	0			

Figure 4: Model outputs

4. COMPUTATIONAL RESULTS

Two problem instance sets were used to evaluate the performance of the proposed model and MS Excel and GAMS/CPLEX application. The first test set consisted of 21 single resource and 21 multi-resource leveling problems including up to 20 activites (Mutlu 2010). All of the multi-resource problems included four resources. The sources of the networks for the test problems are shown in Table 1. The number of activities given in Table 1 does not include the start and finish dummy activities. Selected instances have all been tested in a personal computer with an Intel Core2 Duo processor of 2.67 GHz and 6 GB of DDR3 RAM. The weights for all resources were assumed to be 1 and the weights of both objective functions were taken as 0.5.

Computational results for the test problems-1 are shown in Table 2. Optimal solutions were found for all of the test problems-1 within a maximum CPU limit of two hours. The average CPU time for single resource instances was 3 seconds, and the average time for multi-resource instances was 454 seconds.

Network no	Number of activities	Source
1	20	El-Rayes & Jun (2009)
2	19	Stevens (1990 Pg. 172)
3	18	Mutlu (2010 Generated IV)
4	16	Newitt (2005 Pg. 82)
5	16	Mutlu (2010 Generated VII)
6	15	Hinze (2004 Pg. 152)
7	15	Stevens (1990 Pg. 97)
8	14	Mubarak (2004 Pg. 61)
9	14	Mutlu (2010 Generated III)
10	14	Mutlu (2010 Generated VI)
11	13	Mutlu (2010 Generated V)
12	13	Son and Skibniewski (1999)
13	13	Leu (2000)
14	12	Newitt (2005 Pg. 121)
15	11	Harris (1990)
16	11	Son and Skibniewski (1999)
17	11	Mubarak (2004 Pg. 67)
18	10	Demeulemeester (2002)
19	8	Mubarak (2004 Pg. 217)
20	6	Mutlu (2010 Generated II)
21	5	Easa (1989)

Table 1: Sources of the networks for the test problems-1

The second instance set inluded 48 problem instances including 30 activities and four resources. First instance of each problem set (j301_1, j3011_1, …, j3048_1) were selected problem instances of Kolisch et al. (1999) to form the test problems-2.

	Problem	Number of activities	CPU time (seconds)	
			Single resource	Multi-resource
1	El-Rayes & Jun (2009)	20	2	42
2	Stevens (1990 Pg. 172)	19	4	2715
3	Mutlu (2010 Generated IV)	18	2	4
4	Newitt (2005 Pg. 82)	16	3	497
5	Mutlu (2010 Generated VII)	16	4	13
6	Hinze (2004 Pg. 152)	15	1	2
7	Stevens (1990 Pg. 97)	15	4	3685
8	Mubarak (2004 Pg. 61)	14	4	97
9	Mutlu (2010 Generated III)	14	1	3
10	Mutlu (2010 Generated VI)	14	7	2117
11	Mutlu (2010 Generated V)	13	2	5
12	Son and Skibniewski (1999)	13	6	19
13	Leu (2000)	13	22	302
14	Newitt (2005 Pg. 121)	12	1	2
15	Harris (1990)	11	1	3
16	Son and Skibniewski (1999)	11	2	12
17	Mubarak (2004 Pg. 67)	11	1	1
18	Demeulemeester (2002)	10	2	6
19	Mubarak (2004 Pg. 217)	8	1	1
20	Mutlu (2010 Generated II)	6	1	1

	Problem	Number of activities	CPU time (seconds)	
			Single resource	Multi-resource
21	Easa (1989)	5	1	1
Average process time (sec.)			3.4	453.7

Table 2: CPU times (in seconds) for the test problems-1

	Problem	Number of activities	CPU time (seconds)
1	j301_1	30	170
2	j302_1	30	257
3	j3020_1	30	3850
4	j3021_1	30	200
5	j3041_1	30	35

Table 3: CPU times for the test problems-2 with optimal solutions

Only five problems were solved to optimally out of 48 instances within the CPU limit of two hours. The CPU times for these five problems are presented in Table 3.

5. CONCLUSIONS

RID-MRD metric was introduced in recent years as an alternative leveling metric to achieve robust schedules to maximize the efficiency of resource utilization in construction projects. In this study, a mixed-integer linear model is developed to solve RLP to optimally by using RID-MRD as the objective function. GAMS/CPLEX solver program is applied to solve the problem instances. In order to have a simplified application the model is integrated into MS Excel software.

Computational results indicate that by using the proposed model and GAMS/CPLEX solver problem instances up to 20 activities and four resources can be solved to optimality within a reasonable CPU time. Despite the fact that resource leveling problem is NP-hard, development of fast and efficient exact algorithms is crucial from a practical standpoint and is essential to evaluate the performance of heuristics accurately. Modeling of other resource leveling metrics, e.g. release and re-hire (RRH), and improvement of existing linear models are some of the potential areas for future research.

ACKNOWLEDGMENTS

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FEASIBILITY STUDY FOR ROBOTIC FAÇADE UPGRADING AND MAINTENANCE

Kepa Iturralde
University of the Basque Country, San Sebastian, Spain, kepaiturralde@coavn.org

Thomas Bock
Technische Universität München, Munich, Germany, thomas.bock@br2.ar.tum.de

Kazuyoshi Endo
Kokaguin University, Tokyo, Japan.

Thomas Linner
Technische Universität München, Munich, Germany

Christos Georgoulas
Technische Universität München, Munich, Germany

Abstract

This research focuses on a cost analyze of a hanging robot. This robot is willing to be used for adding a new layer on the existing façade and the maintenance of this layer. The robot has been preconfigured to perform three main tasks. It should upload the elements and anchor them to the existing façade. The robot should maintain the upgraded façade properly. Additionally, if the circumstances require it, the facade can be removed by the robot. The involved kinematics has to be adapted towards an optimal façade solution, and the façade elements have to be designed according to the robot's peculiarities and its desired performance. A simulation has been conducted in order to approve its operability. An orthogonal foldable robot has been conceived, consisted of three frames, each one for a defined purpose. The results of the proposed approach show that operational time per worker decreases around sixty percent compared to manual façade refurbishment. The cost efficiency of this new robotic system is compared to the existing manual systems. The proposed research aims to develop a system that efficiently addresses the automated process, by introducing a series of factors for a competitive solution compared to manual process. By focusing on the façade upgrading, a double skin technical façade can be introduced as a novel solution for obsolete facade lacks and pathologies.

Keywords: Suspended Robotics, facade, automation in construction.

1. INTRODUCTION

Most of the existing buildings need to be renewed or adjusted in order to adequate to the involving needs of the inhabitants. Although, refurbishment processes are dealt many times in an approach that can be considered far from efficient (Iturralde, 2012a).

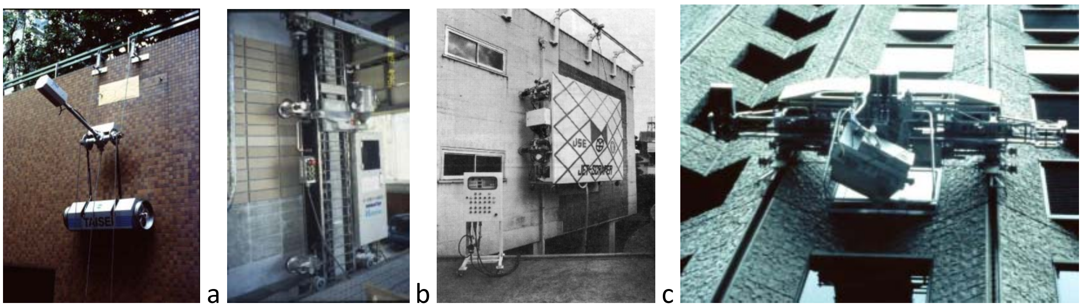
Until today, the development of prefabrication, standardized, modular and automated construction systems have been focused mainly in the construction of new buildings. Automated construction reduces the required costs and time concerns, as well as enhancing the on-site accuracy and safety. There is a potential to utilize these features on automating and robotizing the renewing and maintenance of buildings as well (Iturralde, 2012 b). Apart from being a mere reproduction of the original state of the building, the refurbishment can considered as a choice for ameliorating the built environment where people are used to live in. Basically, the refurbishment can comprise a choice for introducing new building upgrading concepts. There are some universal needs for that. On the one hand, saving or self-generating energy could be an interesting idea. In other words, renewable energy generation systems could be integrated in the building. On the other hand, the materials and elements used for the refurbishment should assist in a flexible and straightforward maintenance in the future. Finally, the added elements should be removable and recyclable. Such a system should be also designed in a way to present flexibility and compatibility with other building systems.

The ``Automated Process of Building Refurbishment´´ can have many points of view or interpretations. In order to avoid misunderstandings, the definition of ``Automated Process of Building Refurbishment´´ is sorted out with the next process description:

The process should start with the data collection of the building. A proper automated refurbishment process is grounded on advanced software and robotics technologies; therefore it also needs to be based in a detailed and exact measurement. Geometrically irregular buildings and land must be adapted to the system. Afterwards, a proper and accurate 3D model using software techniques such as BIM [Building Information Modeling] is required. The project, drafted in 3D, should facilitate the manufacturing of elements by robots. Thus, it should be noted that during the on-site assembly, the components must be rapidly and efficiently handled, using automated tools.

1.2. Previous experiences: façade upgrading with robotics.

The already developed technologies (Bock, 2007) for facade installation and de-installation are an interesting background for achieving a new research project. All of them are applied in Japan.



a b c d

Figure 1: (a) Facade inspection Robot Taisei. (b) Facade Tile de-installation/installation robot. (c) Facade delaminating Robot by Takenaka. (d) Facade Painting Robot by Taisei. All copyrights by Thomas Bock.

Besides, if we have an overlook to processes of adding a second layer in existing facades in Europe, scaffolding or cranes are used normally.

A proper anchoring system for the façade will be required in order to develop our own systems. The already developed Fast connectors systems are interesting for this research (Bock, 2003).

2. RESEARCH SCOPE

The proposed research is mainly focused on buildings with solid facades. The article discusses the possibility of automating the refurbishment processes of buildings with **brick or concrete facades**. Thus, the façade elements have to be adequate enough for anchoring on them an added layer. Drilling operations on the existing façade elements is a requirement of the proposed approach.

The buildings should not have several damages or defects. The reparation related to structural damages is not considered on this approach. The facades objected to the proposed system comprise elements of relatively straightforward and simple geometry. An accurate diagnosis of the facade should be made in advance in order to consider a façade as a defect-proof layer.

3. PREDESIGNED ROBOT: KINEMATICS

According to the required functionality, a multifunction suspended robot has been predesigned. The kinematics of the robot is further explained in a paper accepted on the ISARC 2013 congress.

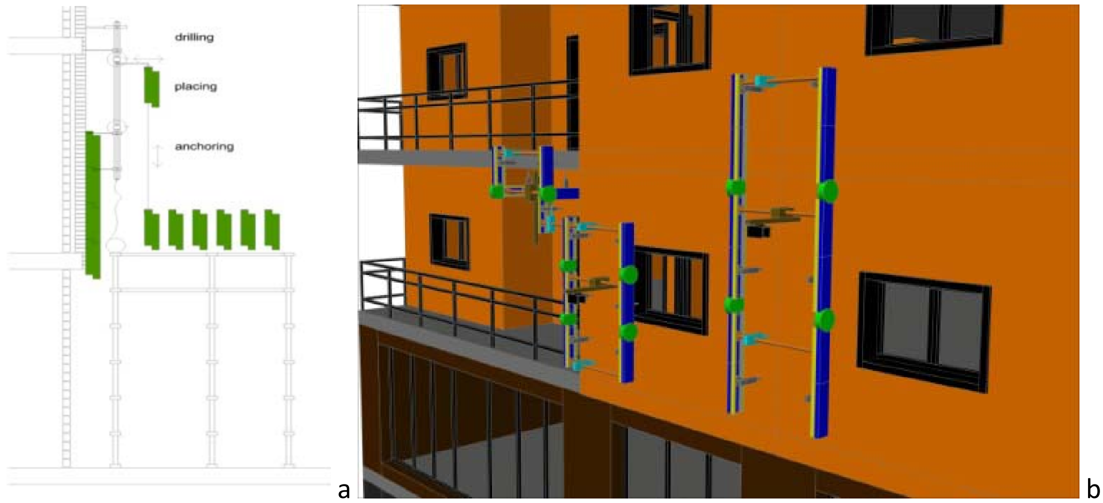


Figure 2: (a) Predesigned robot's cross section, operating in a facade (b) Perspective of the robot, placed in different parts of the façade.

The objectives of such a system comprise:

- Uploading elements from the ground level.
- Placing, anchoring elements on the existing façade.
- Materials/maintenance/dismount/ double skin technical facade.
- Drilling / plug insertion / fixation of façade panel.

As a brief explanation, it can be advanced that the robot is based in a three piece frame. Each frame can rotate from the adjacent one in order to climb on different balconies, terraces and other horizontal elements. Each frame has a different end-effector. The upper frame is the one for drilling. The medium frame is for positioning the facade element and the lower frame is the one that anchors the element to the existing facade. The robot will perform and anchor the elements in vertical rows.

If the building facade imposes severe defects, especially structural ones, a concrete-composite material must be spread on the façade in advance. Such a system, able to evaluate the façade adequacy and appropriateness comprises a future step of the proposed research.

4. PREDESIGNED ROBOT: TIMING AND COSTS

In order to check the performance of the robotic device, a quantitative comparison of manual vs semi-robotic operation is depicted.

The data regarding to the existing manual performance for façade upgrading have been collected from two construction companies in Spain. The data refer to the year 2012. Final prices, timing and costs have been given by those companies. Those data differ from one project to the other. An average of all the received data has been considered.

In order to prove the validity of these prices within the surrounding European countries, those data have been checked out with the construction database in United Kingdom (BCIS,2012) and Germany (BKI, 2010, 2012). The pricing differences are not bigger than 20%.

	m sq / worker hour	worker hour / m sq	m sq /worker year
Manual	0,63	1,60	1.062,50
Semi- Robotic	2,00	0,50	3.400,00

Table 1: Worker installation averages

In the case of the robotic performance, operations time per worker decreases around 70 percent compared to manual work. Let's make a supposition, in which a machine, for now, will need the guidance of a technician all the time.

The robot would handle elements that need to be previously modified for the required purpose. This process can be performed in a workshop, using a CNC or an industrial robot.

According to the table, 1.6 worker hours per m^2 will be required. The multitask hanging robot could be around 0.5 worker hours per m^2. The differences could be even bigger if we take into account the finishing operations in the windows casings.

If we consider that a working year has around 1.700 hours, 1062.5 m^2 per year are installed manually per worker. Instead, a worker could install 3400 m^2 every year in the automated case.

The differences could be bigger if the predesigned robot could be prepared with bigger automation. If one technician could operate with two or more robots each time, differences should be much bigger.

5. RESEARCH QUESTIONS

In order to make a step further in the research, we need to estimate the involved kinematics and how much time and money we could save. Could we predict or estimate the cost of the robot if we take into account the return of investment based on one year? Which are the factors for a successful development of an automated refurbishment system, depending on its typology and economical and technological context? The quantity of investment a company can do is related on the saved money the investment would generate. We should approximate to the cost of the automation of the process in order to know how much a company is willing to invest in order to automate the façade upgrading system. A successful application of the research requires the investment return.

Once we know how much a company could invest on this, we can calculate how much the investment on the R&D in for the specific development could be. Could it be correct if we design the robot according to the benefits we may gain by automating the operation work?

Another question is if a big company could be interested on such a system. Maybe it is more suitable for Small and Medium Enterprises (SME). We will further analyze a company that installs or upgrades 10.000 m^2 facades per year. Let's consider that the company employs 12 workers, 10 on-site (7 of which are sub-contracted) and 2 at the technical office. They install massively produced materials (ulma, sto, fabeton, trespa and others.)

6. COST SAVING ANALYZE

6.1. On-site labor cost

According to the kinematics of the robot, if an enterprise installs 10.000 m^2 per year, three workers could be needed using the new system. Almost 10 workers are needed for operating manually.

	Workers needed on site	Labour cost per year	Scaffolding cost per year	Material production cost
Manual	9,41	512.000,00	50.000,00	400.000,00
Semi- Robotic	2,94	200.000,00	10.000,00	434.000,00

Table 2: Supposition for a company that installs 10,000 sq meters every year. 100 euros per sq installed in façade.

Let's say the final solution cost is around 100 € per m^2 in both manual and robotic cases. If an enterprise installs 10.000 m^2 per year manually, labor cost would be up to 512.000 (if we consider 32 € per hour).

In the case of robotic labor cost per hour should be bigger, in the sense that the worker will need better skills. Let's say workers earn 25% more (40 euro per hour) in the case of the robotic assembly. 200,000 euro would be required.

We can consider that scaffolding is just 5% of the total cost when installing the added facade layer manually. The robotic system will need scaffolding just on the underground, for security purposes. We can consider that buildings normally have five stories. So, the cost for the automated system can be taken as 20% (1/5) of the manual system.

6.2. Off-site labor cost

Off-site costs when working manually are not so many. Besides, an automatic system requires prefab elements that have to be prepared in a workshop. A CNC will be required for customizing the elements. If 10.000 m2 of facade installation is required, the CNC should provide at least 6 m2 per hour. It seems more than possible for a standard CNC to produce on that speed. At least one worker will be needed at the industrial robot. This workers salary should be taken into account. Maybe it should be considered that it could be better to subcontract the already mechanized prefab element. The boundary of subcontracting the prefab element will be depending on the CNC productivity.

We have not considered the expenses of renting a possible workshop.

6.3. Saved money and possible investment return in one year

If we consider the savings that generates the system in one year, the total sum reaches 318,000 euro for the case of the company that has been analyzed. So, can we implement the system, considering that the investment return in one year has to be 318,000 euro. An estimation of cost has been made in Table 3.

Possible Return on investment in one year	318,000.00
Software and measuring devices cost (estimation)	30,000.00
CNC	75,000.00
Possible Hanging Robot cost per unit (3 units)	71,000.00

Table 3: Investment return in one year. Cost estimation

The measuring devices should be rented for each project. According to the profit estimation, the cost of the robot-machine could be 71,000 euro.

6.4. Company type for installing the system

This kind of activity could be considered as a residual economy. The companies that work with this kind of façade renewing projects are mainly small-medium ones. The quantity of work doesn’t require a big investment. The profits are not so big. The heterogeneity of the possible contracts may not be interested on a big company. It requires constant adjustment of the product.

The companies interested on this kind of refurbishment processes, install around 1.000-30.000 m^2 per year. They use common, massively produced materials, (ulma, sto, fabeton, trespa, others), that require a customization for each case.

This main product could be sold to local small companies that could properly adjust it to each case. Could be a franchise a good solution? For instance: The main company could provide (rent) robots, CNC machinery and façade materials. The local franchise would customize the product to the required façade. Common services (architect, CNC router). The size of the company has to be according to the production line in the workshop, unless the product is subcontracted to another supplier that works with the material. The façade detail has to be simple enough to fabricate it straightforwardly.

Nowadays, those activities need an architect or engineer supervision. An architect could work within a company with 20.000 m^2 per year, meaning that the expenses needed for his or her services could be covered.

6.5. Investment of the refurbishment itself

The building envelope could be considered as a base support of the energy generator devices. There is a universal need for finding new energy sources.

Maybe it is time to consider the building facade (and envelope) as a Support for energy capitation. There are some mechanized and manual examples. But how we could apply it in a fast automated way in the existing buildings? How we could achieve an automated future maintenance of them?

7. CONCLUSIONS

The successful implementation of this hanging robot is conditioned with some facts. We can see that if the regional average salary in construction is less than 20 euro per hour, making such as investment may not profitable. The skills of the workers have to be taken into account too. If the regional educational level is low, to find appropriate people for doing the task can be a difficulty.

Besides, the research has also detected that we need a good BIM-robot coordination. If we use a robotic element, we may have to program it every now and again. A precise BIM-robot coordination is required in order to get a fast performance.

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TOWARDS AN EMBEDDED ROBOTIC ENVIRONMENT (ERE) IN EXISTING BUILDINGS

Kepa Iturralde
Euskal Herriko Unibertsitatea, San Sebastián, Spain, kepaiturralde@coavn.org

Thomas Bock
Technische Universität München, Munich, Germany, thomas.bock@br2.ar.tum.de

Kazuyoshi Endo
Kokaguin University. Japan.

Thomas Linner
Technische Universität München, Munich, Germany

Christos Georgoulas
Technische Universität München, Munich, Germany

Abstract

This article analyzes the possibilities for integrating robotic appliances in the built environment. Since the industrial revolution period, services have been integrated into the building's infrastructure. The building elements could be modified in order to get a better interrelation. An interdependent design between a robotic system and the building elements is proposed. Obviously, there are several options and there is also the necessity to implement an Embedded Robotic Environment. In order to establish a financially efficient approach considering the return on the investment, the robotic system should be multitasking. Additionally, the proposed system could be adapted to the forthcoming elderly society's needs, considering the current demographic change issues. For instance, on one hand it could be used explicitly for construction operations, such as building maintenance and interior maintenance and upgrading. On the other hand, it could be also used for servicing the needs of the inhabitants, such as cleaning, cooking, transporting heavy items or generally assisting in the activities of daily living. It must be noted that the weight of the robot should be as relatively limited, in order not to overload the home environment structure. Adapting such a concept into new buildings by integrating it during into the building construction phase could be possible, but integrating it into an existing building environment will be a tougher issue. The robotic systems will be embedded into building subsystems such as primary systems (structure: columns, beams, structural walls, etc.) interior/exterior walls, suspended / ceilings, raised/ floors, service areas, utilities etc.

Keywords: Building, Systems, Transformation, Adaptation, Embedded Robotics

1.INTRODUCTION

Robotic appliances in the built environment are mainly used for:

- Construction and maintenance purposes. On this paper we will deal with the adjustment or refurbishment of old buildings. There is already some experience on that issue (Iturralde, 2012a).
- Assistance to the Activities of Daily Living (ADLs)(Wiener, J.M. et al 1990). The topic has been already developed before with the name of ``Multi Robotic Assistant System´´ (Linner et al., 2012). We will focus on interior self-deployable robotic appliances.

The main research objective is to integrate both robotized processes in the existing building environment. Historically, old buildings have been constantly readjusted. New installation and services have been inserted in the existing built environment. Initially, they comprised water supply, later electricity and heating systems. Initially, they were considered as foreign tools within the building. Later though, building construction technique was re-thought and re-engineered in order to adapt to the new requirements. New construction systems were adopted to host different services. MEP (Mechanical, Electrical and Plumbing) and ICT already appears in nowadays buildings. Nowadays, we come across cutting edge technologies even in hundred years old buildings. Though, the adjustment of existing buildings to the ongoing technologies requires a customization of the so-called universal installation systems. Some of these appliances have been installed in buildings that were not really prepared for such activities. The insertion of installations in the building environment required a modernization of the different layers of the building.

(a) (b) (c)

Figure 1 Different fan systems: (a) portable (b) ceiling suspended(c) embedded or integrated

As an example, we can see how the fan system, depicted in Figure 1. First, it was just a movable appliance, not really integrated in the building system. Then it was suspended from the ceiling, in order not to disturb and to efficiently remove the heat accumulated to the upper levels of the environment. Nowadays, modern heating air-conditioning systems requires extensive installation spread into the building's infrastructure. In best cases, the systems run between building layers. This concept is quite important. All the elements of the system must be designed and installed in order to allow for straightforward access for maintenance and service operations.

It is clear that in many cases such an installation hasn't been integrated during the construction phase, but is rather performed and regarded as a post-interior finishing operation. The causes are several, such as lack of investment leading to simpler reduced cost design, or geometrically limitations that disable such an installation as an embedded system from the beginning.

2. ROBOTIC ENVIRONMENT PREMISES

In order to get an Embedded Robotic Environment (ERE), we have to seriously consider the following three points. Previous research has already addressed such design considerations (Linner et al., 2012).

- It is not recommendable to install the appliance system on the floor. The robotic appliance could disturb the mobility of the building occupants. Therefore, it is recommended to suspend the robotic system from the ceiling.
- This movable hanging robot, normally needs a mechanized environment, with rails and guides. Somehow, a substructure is needed.
- It is better if this substructure is rigid enough for the robot, in order to allow for a seamless and more efficient operation, regarding the various integrated services and features such a system could comprise.

In order to accomplish these premises, a change in the usual refurbishment process is needed. Nowadays, the usual building upgrading process consists of the on-site manual transformation of the material, which most of the times does not offer the required accuracy. Let's consider that a rigid pre-mechanized and accurate customized system is needed.

3. BUILDING SYSTEM PREMISES

Flexibility. The building elements have to be flexible, not only for the appliances, but also for the continuous upgrading according to the inhabitants requirements. Especially for the ageing society, this may be an issue to resolve. The degenerative health situation of inhabitants needs a constant change in their built environment. Plus, maintaining the existing living context could be proper for the elderly people, since elderly people normally prefer to remain as much individual as possible in their own environment.

Adaptability of the system to the existing context. How? The system has to be **modular** and it has to adapt to the requirements of the inhabitant. The system should offer different variety of services. For instance, some people may require functional transfers, i.e. bed to bathroom. But some other people could be assisted just with a proper lighting. The robotic system needs to be modular and customized, in order to efficiently address all these different scenarios.

Converting an entire living unit (apartment, elderly house, hospital), into a robotic environment, won't necessarily mean that it can comprise the most efficient solution, under all circumstances. A customized approach must be followed according to the explicit needs. Integrating a robotic system in all environments may result in a cost ineffective solution. Instead, the robot could move from one space to other. This generates some problems. For instance, a conventional door can be an obstacle if we want to make a bed-bathroom transfer. That is, the door has to be thought and re-designed accordingly.

4. CONSTRUCTIVE SYSTEM PROPOSITION. EMBEDDED ROBOTIC ENVIRONMENT (ERE)

In order to perform an Embedded Robotic environment, a grid is proposed in the previous researches. The system is already quite defined (Iturralde, 2012a) and we already know the impact on efficiency (Iturralde, 2012b). We do have to adapt to existing buildings. This grid is featured with universal guides or profiles in order to accomplish a common solution. If we design a closed industrialized system, it won't adjust easily to different situations. The system should offer a variation on the same theme. For instance: a Timber structure building does not need such a big rigidity such as a concrete structure building. The system for refurbishment could be similar but there must be different approaches and solutions. If the incurred transport loads are big, the rails may require some maintenance.

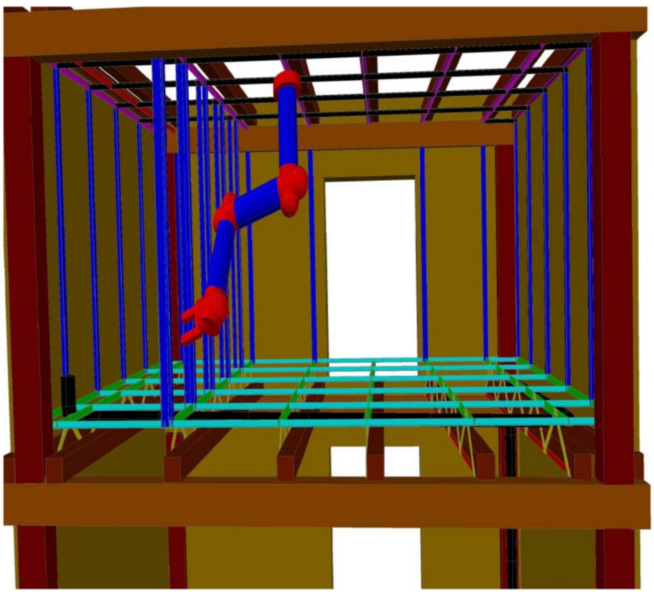

Figure 2: Building renovation using the proposed system. The proposed substructure has different purposes. First it can be used to reinforce the existing structure when needed. Then, it will be used as a support for distribution and services. Finally, the robotic appliances will run along that substructure.

Even more, the structure may need to be reinforced in order to get a more rigid grid in order to avoid excessive oscillation, especially in wooden structure buildings.

The proportion of old houses in a region can also be considered, if there is a need for refurbishment. The automation of the process could greatly assist on the inefficiency of the sector. In regions where a major number of new buildings is required, keeping the existing building functional really does not make an impact.

In order to install the new Embedded Robotic Environment in the existing building, some previous works are needed. Basically they will consist of little demolition works and installation dismantling. How to do all those will be explained further on the next publications.

In Figure 2, we can observe the architecture of the proposed robotic system for refurbishment, where the previously mechanized elements can be assembled by the robotic manipulator. The already installed infrastructure (rail grid) used for the refurbishment process, could be also later used for assistance in the activities of daily living, Figure 3.

5. RESEARCH QUESTION

Which are the facts for getting a successful Embedded Robotic Environment in an existing building?

In other words:

Which are factors for a successful development of an automated Embedded Robotic environment depending to its typology and economical and technological context?

If the proposed system is not competitive, maybe it is only adaptable to certain economic backgrounds. The competitiveness of the system should be compared to manual processes. There are two aspects to consider. First, we have to consider the base construction system with an ordinary refurbishment process. Then, we have to take into account the investment cost f the assistance robot.

Return of the investment:

- Labour cost saving: when could we have a return? Which is the time window?
- Cheaper and more efficient maintenance: when could we have a return? Which is the time window?

6. COST ANALYSIS FOR A SUCCESSFUL IMPLEMENTATION OF THE ERE

Although the aforementioned assumptions are uncertain yet, we can say that the proposed system requires quite a big investment. So, in order to be competitive, the system has to work in built contexts where there is quite a big expending and there is a big manual work force. We will focus on the elderly nursing homes.

Let's consider that a person has to move to an elderly residence, leaving his home and acquaintance contest. A person usually stays in such an environment for approximately five years before statistically passes away. According to statistical data (Tortosa et al. 2011) (Eurostat 2012), the European cost in a nursing home could be considered, as average, 1.875 euro per month. It is also mentioned (Tortosa et al. 2011) that 45% of the cost is related to direct assistance personnel. 20 % is related to non-assistance personnel. 4% is related to building maintenance. Thus, 70% percent of the cost is related to the assistance of the person and the maintenance of the place where the person stays. In one year, those costs could be around 22.500 euro per person, and in five year the cost reaches up to 112.500 euro.

It's easy to say that the proposed system has to be at least cheaper than the 112.500 euro in order to be competitive. What are the expenses we have to cover with that amount?

- Building retrofitting of the existing homes where elderly people live
- Inhabitants assistance

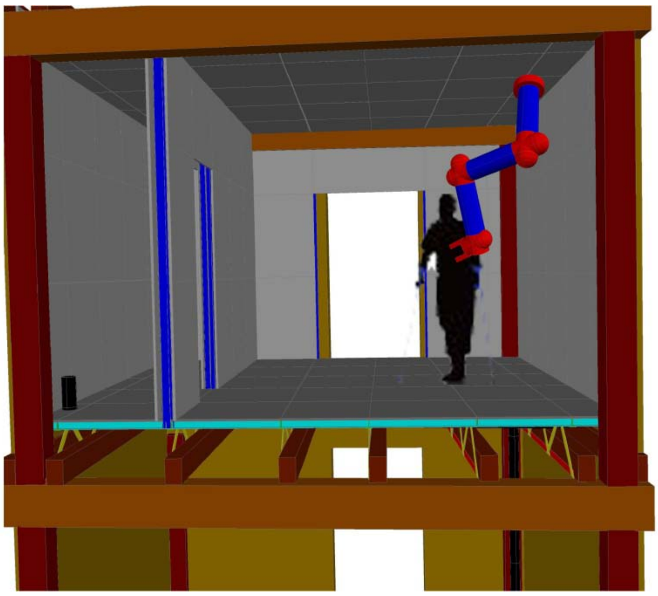

Figure 3: Elderly people assistance using the proposed system.

Using conventional methods, a complete inner-refurbishment process, including new installation, new distribution, insulation etc. could be around performed with an estimated cost of 800 euro per m^2 as an average (Iturralde, 2012a) in Europe (including all expenses). One of the reasons for elderly people to be forced to live in an elderly residence is that their homes are not really prepared for their upcoming needs and effects of aging. An upgrading is required.

Depend in the automation level, the proposed system, will require around 1.200 euros per m^2. If we consider that the elderly live in a flat, comprised with by a big bedroom (24 m^2), a proper bathroom (6 m^2) and a kitchen (10 m^2), we have to adequate a 40 m^2 space, which will cost around 48.000 euro. Thus, the remaining 64.500 euro can be utilized for populating the environment with assistive robotic systems.

We have to take into account that the future maintenance and upgrading will be easier and cheaper. Only new pre-mechanized elements will be required if a transformation of the inner distribution is needed. So the initial investment could be recovered again.

It is a reversal system: if the inhabitant passes away, the home will be needed for some other purposes. We can imagine a young couple enters to live. The distribution system can be easily adjusted with the pre-mechanized element. They can be assembled on site with robotics, or manually.

7. CONCLUSIONS

During history, buildings have changed their original systems in order to adapt to new situations. Next step seems to be an automated or robotic environment. A reasonable adjustment of robotics in the built environment will need an upgrading in the construction system. If we want to achieve a universal system, modularity and customization should be considered.

If we want to achieve a successful system, the application has to be designed according to the technological and economical environment of the region. If we design a system that is too expensive for regional background, it won't succeed. Besides, if we achieve a process that ameliorates the competitiveness of the building renovation and the caring system, the system could feasible.

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THE CURRENT SITUATION OF UNIT PRICES, ETC. IN SUBCONTRACTS OF REBAR WORK: A HISTORY BASED CASE STUDY OF A REBAR COMPANY

Jun Iwamatsu
Research Institute on Building Cost, Tokyo, Japan, iwamatsu@ribc.or.jp

Tetsukazu Akiyama
Toyo University, Saitama, Japan, akiyama@toyo.jp

Hirotake Kanisawa
Shibaura Institute of Technology, Tokyo, Japan, kani@sic.shibaura-it.ac.jp

Masao Ando
Chiba University, Chiba, Japan, m.ando@faculty.chiba-u.jp

Abstract

One of the major factors that make the Japanese construction production system vulnerable is the multi-layering of subcontractors. It has been pointed out frequently that business transactions in such multilayered systems often lead to pricing and scheduling difficulties due to the nature of the relationship between contractors and subcontractors. However, such circumstances have seldom been examined quantitatively. Therefore, it has been difficult to study them objectively and to improve the system.

Nonetheless, we were able to obtain a set of relevant data, which we closely studied and analyzed to examine such transactions. The company that we examined, which we call Company A, is a rather large rebar company located near Tokyo. We statistically analyzed the firm's 650 contracts over the past decade and discovered useful facts.

Keywords: specialty contractor, statistical analysis, unit price, seasonal fluctuation, duration.

1. RESEARCH OBJECTIVES AND MATERIALS

One of our research objectives is to understand the problems that are associated with the treatment of skilled construction workers in Japan. Discussions regarding this issue often lack any firm knowledge of reality. Therefore, we aim to better our understanding of such problematic treatment by examining the current situation of the construction industry from the perspective of specialized construction firms.

In the fall of 2007, we surveyed six relatively large-scale construction companies that specialize in rebar work in and around Tokyo. Although detailed descriptions of these companies are not relevant here, it should be noted that these companies are favored subcontractors[1] of influential general contractors. In other words, they are first-tier subcontractors that are powerful enough to hold executive positions in collaborative subcontractors associations[2].

As part of this survey, we obtained the contract history of one rebar firm; we will refer to this firm as Company A. This contract history differs from ordinary ones in that it contains contract prices, quantities of rebar used in each project and work durations, along with the typically given data (names of the clients and projects). Moreover, this data spans over the ten-year period from 1997 to 2006, and is very detailed (except in the case of some small projects). In other words, this data is a valuable resource that shows what kinds of subcontracts this rebar company signed with prime contractors (general contractors and local construction companies). In this study, we statistically analyzed this data. Table 1 shows a profile of Company A.

Location:	Headquarters in Tokyo; Processing plants in 2 locations
Foundation:	1975 (Approximately)
Capital:	50 million yen
Specialization:	Rebar work (Permit granted by the Governor of Tokyo)
Employees:	160 (30 in processing plants, 100 on-site, 30 in other locations); 30 second-tier subcontractors (all numbers are approximate)
Work description:	Its principal client is one large general contractor. Its work consists primarily in building construction.

Table 1: Profile of Company A

An overview of Company A's contract history is as follows:

1. Data: 650 contracts (some small jobs were omitted)

2. Duration: 1997 - 2006 (ten fiscal years)

3. Contents: As shown in Table 2. The data recorded in this contract history is the complete record of Company A's business transactions during that decade; the annual totals of the project prices recorded in this data nearly match the company's annual total sales.

[1] A favored subcontractor, or *meigi-nin* in Japanese, is a subcontractor that has won the trust of a prime contractor as the result of their long-term working relationship. A prime contractor gives priority to its favored subcontractors when subcontracting projects.

[2] A collaborative subcontractors association, or *kyoryoku-kai* in Japanese, is an intermediary organization consisting of first-tier subcontractors that provide services to a common general contractor.

Year	*Client*	*Project*	*Project Price*	*Quantity*	*Duration*
	Company name	Building name	Price given in ten thousands of yen	tons[3] of rebar	month/year - month/year

Table 2: Description of the Data in Company A's Contract History

Further description of the items in this contract history is given below.

– Project price: the actual contract prices after final adjustments (this price excludes sales tax)

– Quantity: adjusted quantities

– Duration: the length of time during which Company A actually provided rebar work services

The unit price (given as ten thousands of yen / ton) of a project is calculated from the project price and the quantity of rebar used. Although further details will be discussed later, it must be noted here that some very high unit prices should be considered as exceptions, due to the fact that they include both material and labor prices. In such material-and-labor contracts, Company A has to purchase rebar materials for the projects because either their client firms do not have sufficient credit to purchase materials themselves or because the projects are very small in scale. In transactions with large general contractors, these contractors usually provide Company A with the materials. Therefore, unit prices in such contracts only include labor.

2. TYPES OF DATA ANALYSIS

Using the data from the above-described contract history, it was possible to calculate the unit price of the rebar work and to study its fluctuations over time. This same data could also be analyzed in terms of the client firms. While most of the projects carried out by Company A were building construction, some project names suggest that they were either special or public works construction. Although the project names do not indicate the exact nature of the work involved, such projects that were suspected of being exceptional were excluded from certain analyses. The fact that this contract history provides work durations is valuable, but this data is given in terms of months and thus lacks precision. Furthermore, findings from this contract history cannot easily be generalized to the entire rebar work sector because the data comes from just one particular company. Therefore, the data used in this study has both

[3] Here and throughout the paper the term "ton" is used to refer to metric tons.

strengths and limitations; its analyses resulted in some interesting findings, but the scope of the results of this study is somewhat limited.

We carried out the following analyses, and this paper reports the findings of some of them:

– Fluctuations in contract prices, quantities, unit prices and other factors over time;

– Fluctuations in the degree of exclusivity of Company A with a single general contractor over time;

– Frequency distributions of per-contract quantities and project prices;

– A study of whether unit prices vary between contracts with different contracting firms, and whether they fluctuate between different contracts with the same company;

– A study of whether unit prices change with the quantity contracted (for example, does an economy of scale exist?);

– An analysis of seasonality (whether the quantity of work begun and the project unit price vary from month to month);

– The relationship between the quantity (or the contract price) and the duration of the work; and

– Whether actual unit prices differ from the market unit prices, which are used to calculate the ceiling prices[4].

Price analyses (e.g. unit price analyses) over a span of approximately ten years usually require adjustments by the construction price deflator. In our case, however, the deflator varied very little, between 102.8 in 1997 and 97.4 in 2002 with 2000 as the base year. Thus, we determined that this variance was not significant enough to make special adjustments to the data.

3. STATISTICAL ANALYSIS OF COMPANY A'S REBAR WORK CONTRACTS

3.1. Fluctuations in Company A's Work Performance Over Time

Figure 1 shows the fluctuations in Company A's performance over the past decade. Company A is a relatively large rebar company. It has between 40 and 100 contracts per year, and its

[4] A "ceiling price" is the pre-set cost-of-construction as reasonably predicted by owner-side engineers using the provisions in the Public Accounting (Financial) Law (enacted by the Japanese government in 1889). Unlike in other countries, there is a provision in this law requiring that this pre-estimated amount should stay under a certain ceiling. This results in the rule that the successful tender price should not exceed the ceiling price.

annual earnings fluctuate between 1.4 billion and 2.4 billion yen. The company's quantity contracted (i.e. the weight of the rebar used) ranges between 31,000 and 48,000 tons per year.

We statistically analyzed Company A's contract history to see if it contains any particular tendencies. We first examined Company A's contracts by scale. While the company's contracts vary widely in size, an overwhelmingly large number of them are small contracts (see Figure 2). Overall, the average quantity contracted is approximately 616 tons (with a median of 307 tons), and the average contract price is approximately 28 million yen (the median is approximately 14,070,000 yen). The quantities contracted and contract prices both declined slightly in recent years, perhaps because Company A signed more small contracts to maintain its business or the contracting firms are pressuring them to lower their project costs. (We will discuss unit prices later.)

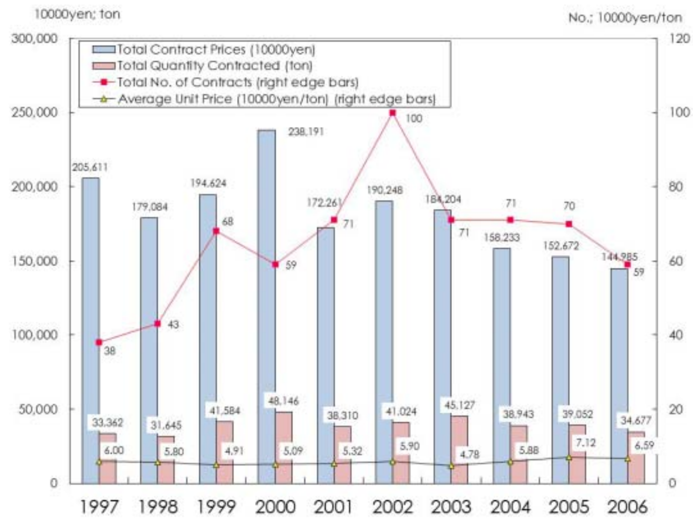


Fig.1: Fluctuations in Company A's: Annual Contract Prices, Quantities, Number of Contracts and Average Unit Prices

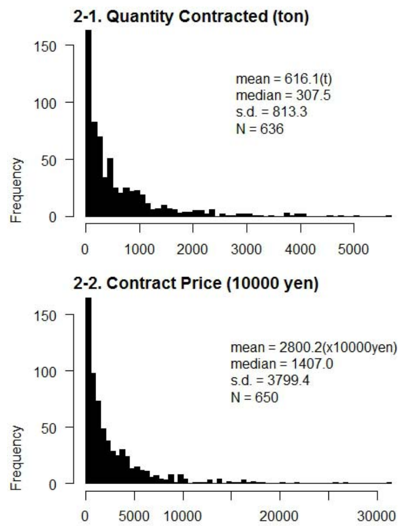


Fig. 2: Histograms of Company A's Per-Contract Quantity and Price

3.2. Analysis of Company A's Clients

Company A had contracts with 26 firms during the decade covered in the data. While most of the jobs were small-scale and sporadic, Company A had an on-going relationship with four firms, including one large general contractor (indicated as GC17 in Figures 3-1 through 3-4). Figures 3-1 through 3-4 show Company A's relation to all of the contracting firms in terms of: number of contracts, quantities contracted, contract prices and unit prices. These graphs illustrate the nature of Company A's relationship with each firm.

As shown in Figure 4, Company A's degree of exclusivity (in terms of the proportion of its total income) with GC17 fluctuated between 70% and 97%. Establishing close relationships with a small number of general contractors is not unusual for first-tier rebar work subcontractors (See Reference 1). This phenomenon began after the end of World War II when rebar companies assumed the role of specialized framework builders and were closely associated with general contractors. In fact, all of the surveyed companies in this study are so-called favored subcontractors, and they are powerful members of collaborative subcontractors associations that are each associated with a large general contractor.

Company A had only one or two contracts with some firms during the recorded period. These firms are mostly construction companies located near Company A. According to Company A, they have a policy to not neglect the demands of such neighboring firms.

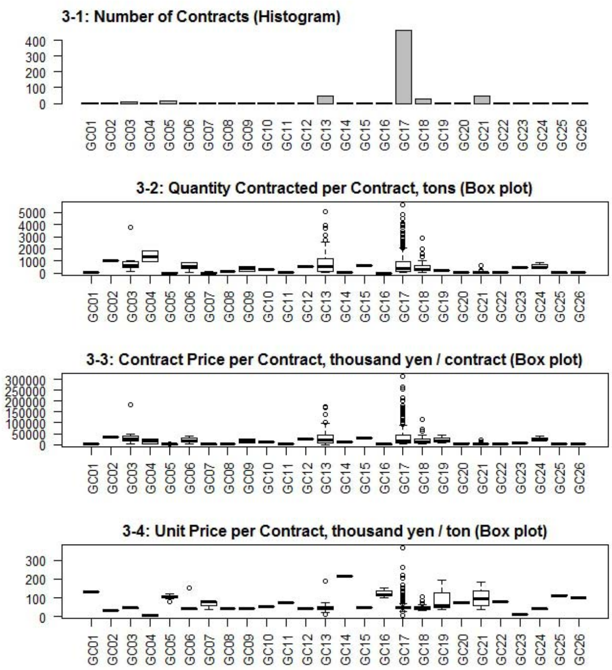


Fig. 3: Company A's Statistics by Contracting Firms (10 years)

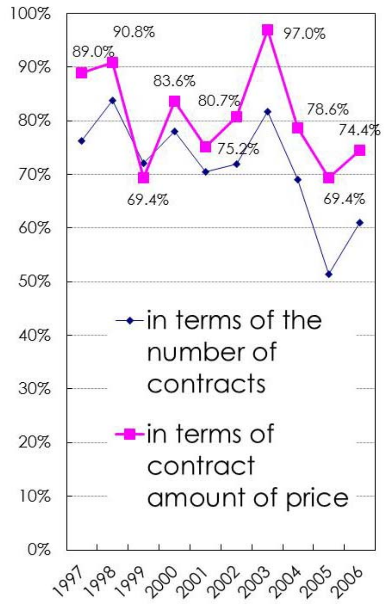


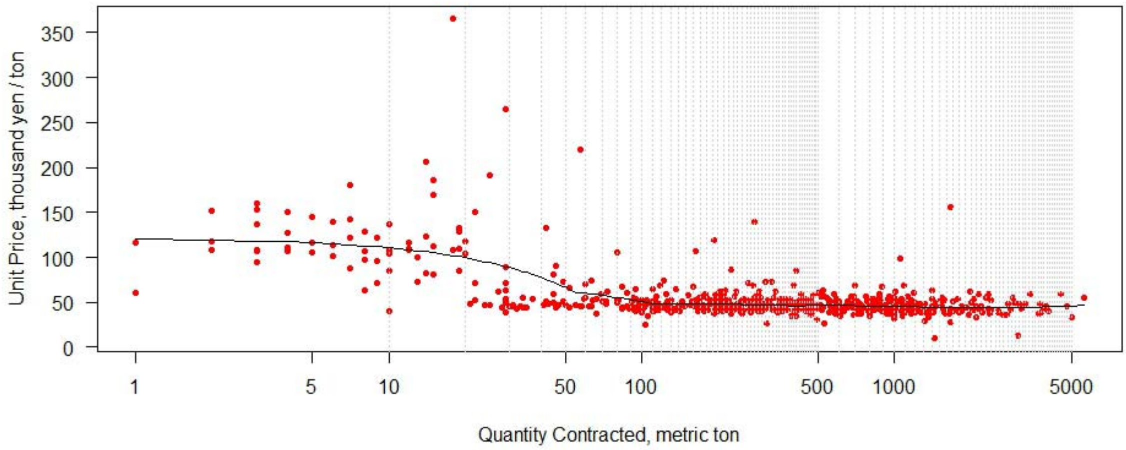
Fig. 4: Fluctuations of Company A's Degree of Exclusivity with the Main General Contractor (GC17)

3.3. Relationship Between the Quantity Contracted and the Unit Price

Generally speaking, the quantity contracted is believed to affect the unit price because of the economy of scale. We examined our data to see if this holds true in the case of Company A.

Figure 5 illustrates the relationship between these two values in the context of ordinary projects (excluding public works). A concentration of points can be observed at around 50,000 yen, but higher unit prices are recorded for jobs with low quantities contracted. Therefore, the data at first glance appears to show the economy of scale. However, Company A informed us that some of the small projects were material-and-labor contracts, implying that those unit prices included the cost of materials and labor. Furthermore, they also explained that some unit prices are unusually high because of high contract prices. These high prices were due to the fact that they either included fees from other projects done for the same firms around the same time or were for projects with materials, which were difficult to manipulate. Although such exceptional cases are not easily distinguishable in the data, they are nonetheless important factors that caused unit prices to be skewed.

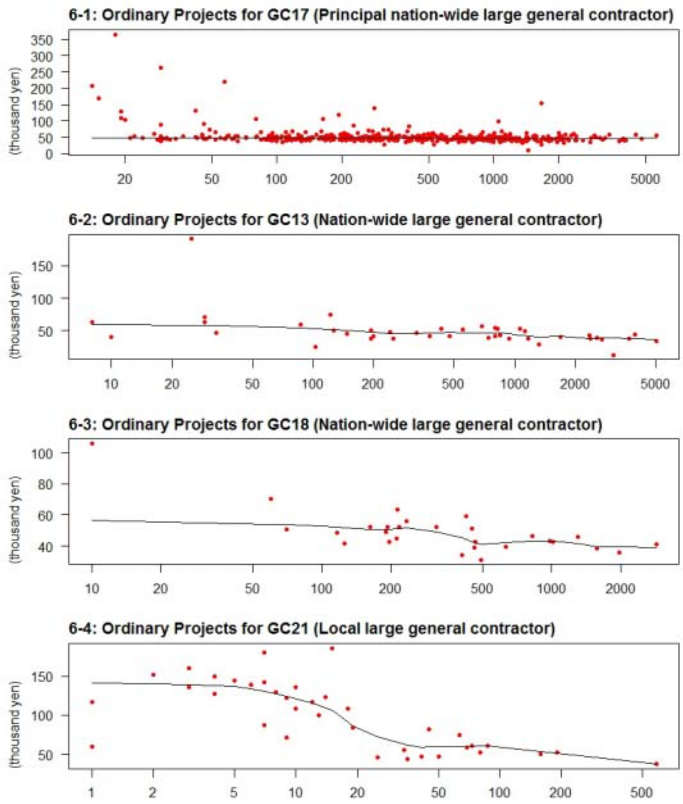
Therefore, although small projects do appear to be comparatively more costly, we cannot establish that such a tendency in fact exists. For quantities of 60 tons or more, the unit price trend line becomes flat. We thus conclude that the economy of scale does not exist for unit prices in that upper range of quantities contracted.



Note: Although the unit price appears to be higher for quantities contracted smaller than 100 tons, this apparent tendency is not conclusive as some of those unit prices include both material and labor costs. Various explanations are plausible for the points far from the regression line, but the specific reasons for each case are unknown. (The figure includes a LOWESS curve. N=608)

Fig. 5: Quantity Contracted and Unit Price (Including only ordinary projects; this exclusion holds for all the remaining data presented unless otherwise mentioned)

The same relationship (quantity contracted versus unit price) for each of Company A's main clients is shown in Figures 6-1 through 6-4. Because Company A has established contractual terms with each client, the unit price for each firm should fluctuate relatively little between contracts unless project-specific conditions cause alterations in the price. Figures 6-1 through 6-3 refer to transactions with three different nation-wide general contractors, and their unit prices only include labor. These labor-only unit prices do not vary greatly from one contractor to another. Figure 6-4, on the other hand, is of Company A's contracts with a local general contractor. This graph's unit prices are segmented into two groups because some include both material and labor while others include only labor. We could not classify this data into the two different categories, as it was not possible to get this information from Company A.



Note: All unit prices include only labor, except for some in Figure 6-4 (GC21) that include both materials and labor. (LOWESS curve)

Fig. 6: Quantities Contracted and Unit Prices (By main contracting firm; ordinary projects only)

3.4. Fluctuations in Unit Prices Over Time

Figure 7 shows the quarterly fluctuations in unit prices (ten thousand yen / ton) in contracts with the principal large general contractor (GC17). Until 2005, the unit price gradually declined, but then it rebounded slightly in 2006. This rise was due to a severe shortage of rodmen (see Figures 8), which was especially problematic in the Kanto region. This scarcity was comparable to that experienced during the bubble period in Japan. However, this problem has been resolved, i.e. December of 2007 recorded a negative shortage, and this factor is not expected to be the cause of increases in construction costs any longer. Rodmen scarcity is believed to have lessened in recent years because of the reduction in the number of building confirmations and inspections after the Revised Building Standards Act came into effect in June of 2007.

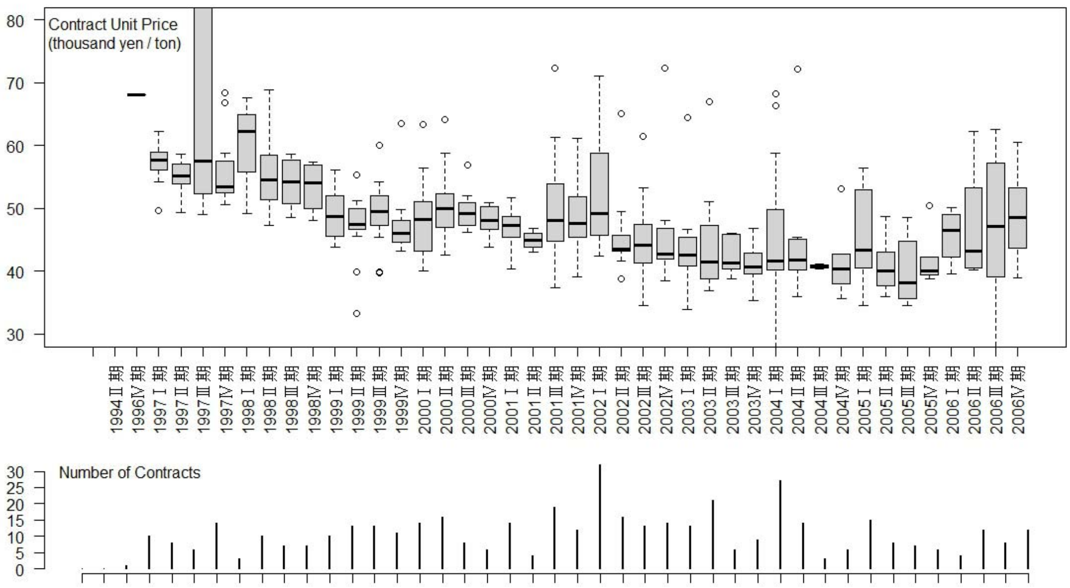


Fig. 7: Quarterly Fluctuations in Unit Prices in Contracts with GC17 (Box plot)

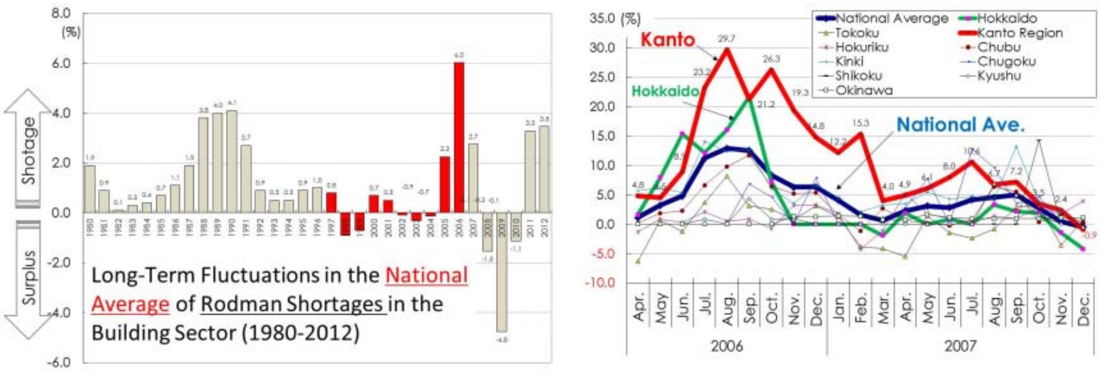


Fig. 8: Fluctuations in Rodman Shortages in the Building Sector (by National Average and Region)

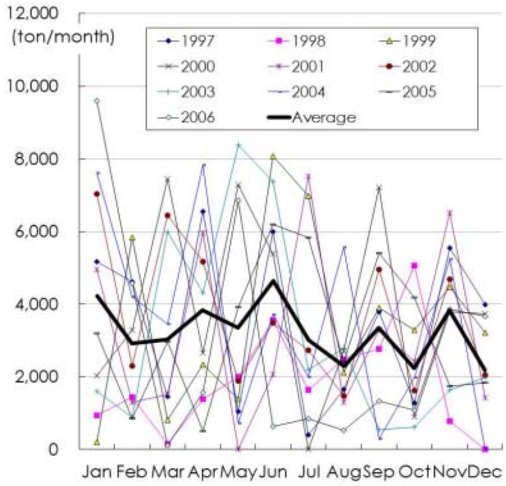
Note: Figures created from the monthly data in the Survey of Supply and Demand of Construction Labor compiled by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of JAPAN.

Interestingly, the shortage of rodmen in the building sector was the worst of all of the shortages of construction workers in Japan in recent years. Other specialties, such as rodmen in public works and timbermen in building work, have also experienced shortages but were not nearly as scarce as rodmen in the building sector. Though rodmen were most scarce in the Kanto region and Hokkaido, this shortage was not as pronounced in the rest of Japan. The shortage of construction workers is an index that varies greatly, as large construction projects can cause drastic shortages of workers in their surrounding areas. Whether 2006's shortage of rodmen (in the building sector) in the Kanto region was due to such circumstances is not known.

3.5. Seasonality of the Work Quantity

Fluctuations in quantities contracted and the quantities executed throughout the year indicate the ups and downs of a company's business; this is also known as the "seasonality of the work quantity." The quantity executed was estimated from the new quantity contracted in each month and the duration of each contract. More specifically, the estimated quantity executed for each month was calculated by simply dividing each quantity contracted by the duration of that project, and allocating that per-month quantity to every month during which the project took place.[5] Figure 9-1 shows the quantities contracted and Figure 9-2 shows the estimated quantities executed from January through December over the decade.

9-1: Quantity Contracted in the Months that Projects were Begun (1997 - 2006)



9-2: Estimated Executed Quantity in the Months that Work was Executed (1998 - 2006)

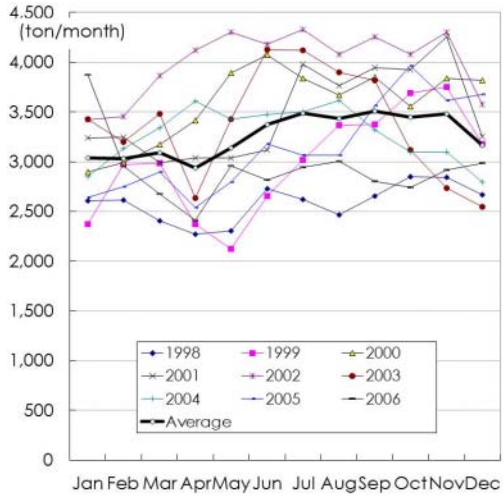


Fig. 9: Seasonality of the Work Quantity in the Months that Projects were Begun and in the Months that Work was Executed

According to the summary of the monthly quantity of new projects (see Figure 9-1), more projects (in terms of quantity) were commissioned during the first half of the year and that number decreased slightly during the second half of the year. However, this tendency is not very clear. The quantity of new work seems to fluctuate rather largely between those months with many new contracts and those with very few.

On the other hand, the summary of the monthly estimation of the quantities executed shows the opposite tendency; this quantity tends to increase during the second half of the year. The range of the variation, however, is smaller than that in Figure 9-1. In other words, the estimated

[5] According to Company A, the quantity of work fluctuates differently in each project and is therefore difficult to estimate. However, they believe that the sum of all of the estimated quantities executed for each month (calculated by a simple division as described in the text) should not deviate significantly from the actual monthly quantity of executed work. Company A's current business objective is to install 3,500 tons of rebar every month, with an annual maximum up to 48,000 tons. (cf. Figures 9-1 and 9-2).

quantity of executed work is rather stable from month to month. This stability is achieved by Company A's appropriate allocations of its resources. Company A seems to adjust when and what projects it accepts in order to maintain a productivity level as close to their highest capacity as possible at all times. This ability is key for a successful specialized company.

3.6. Analysis of the Work Duration

The average duration of Company A's projects was 8.70 months (the average for projects for GC17 was 9.35 months). However, it must be noted that the recorded durations differ slightly from (i.e. are slightly longer than) the actual durations, because the data was given in terms of months (see Figure 10). The relationships between the work duration and the quantity contracted are shown in Figure 11. These figures show that a certain level of correlation exists between the work duration and the scale of the work. However, the points are spread widely in both the vertical and the horizontal directions, and thus no strict correlation can be determined.

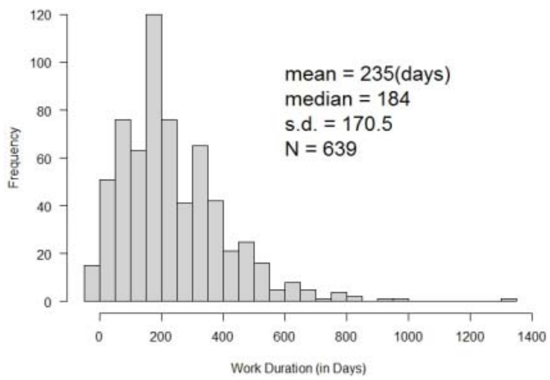


Fig. 10: Distribution of the Work Duration (in Days) (This figure includes all of the contracts contained in the data.)

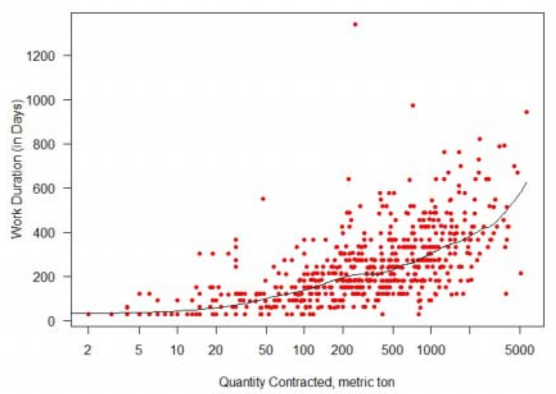


Fig. 11: Relationships between the Work Duration and the Quantity Contracted (X-axis: Corresponding Units)

4. CONCLUSIONS

Because the contract history that was analyzed in this study comes from a single rebar company, our findings cannot be readily extended or generalized. Nevertheless, this study provides a glimpse of the current situation in the rebar work sector in Japan and provides information that is virtually unknown outside the construction industry. We therefore believe that our results are valuable. Below is a summary of our findings:

– Most of the contracts with large general contractors include only labor (materials are provided by the general contractors), while smaller projects for medium to small-size general contractors may include both material and labor (i.e., Company A provides the materials).

– The rebar used in each construction contract is estimated to range between 50 and 200 tons, according to a journal on construction related pricing information (ex. *Kensetsu-Bukka*). However, Company A averages 300 tons in their contracts. (This may be due to the fact that Company A is a favored subcontractor of a nation-wide large general contractor.)

– Unit prices in big contracts (more than 100 tons) become more or less fixed, and thus no economy of scale is observed.

– In the case of labor only contracts, no significant differences in unit prices are observed from one contract to another.

– Starting in the latter half of the 1990's, the unit price of rebar declined. But it rebounded following the shortage of rodmen in the Tokyo area in 2006.

– An analysis of work durations revealed little change in Company A's monthly number of finished projects (quantity of executed work), when compared with the number of projects begun (the quantity of new contracts). In other words, operational resources are being effectively utilized.

– While the duration of a job tends to increase with the cost and scale of the contract, this relationship is not precisely proportional. Actual durations vary greatly from case to case.

Apart from the issues analyzed in this study, many other important factors were uncovered during the interviews. Examples of such factors include: problems related to the treatment (i.e. employment and salary) of the skilled workers who play a vital role in rebar processing plants and construction sites, and the consequent shortage of young workers acquiring such skills, the current situation with foreign trainees and apprentices, and the current atmosphere of subcontracting that necessitates that on-site construction responsibilities be multi-layered. However, we have to leave these topics for another article.

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IMPROVED FIELD APPLICATION OF 4D CAD SYSTEM USING ACTIVE BIM CONCEPT

Leen-Seok Kang
Gyeongsang National University, Jinju, Korea, Lskang@gnu.kr

Hyun-Seong Kim
Gyeongsang National University, Jinju, Korea, wjdchs2003@gmail.com

Hyun-Seok Moon
Korea Institute of Construction Technology, Seoul, Korea, hsmoon@kict.re.kr

Abstract

4D CAD is one of representative functions of BIM system that is being used in the construction phase. This study suggests improved functions of 4D CAD system using active BIM concept. Most of current BIM systems are focused on the passive functions. Passive BIM functions mean that 3D and 4D objects are just used for visualizing the interference status in 3D model and the schedule simulation in 4D model. Nowadays, as the increase in the use of BIM, project managers need additional functions of 4D CAD system after visual confirmation of schedule information. For example, they need a solution for optimizing construction schedule, which can reduce schedule interference and conflict of workspace, from the 4D CAD system. In that case, passive 4D CAD or BIM functions cannot provide an optimized schedule plan in addition to the simple schedule simulation information. However, if they use an active 4D CAD or BIM system, first, it can visualize the schedule interference status. Second, it analyzes an optimized schedule plan that can reduce interference using an optimization process such as genetic algorithm. Finally it can simulate the optimized schedule plan by comparing initial plan. That is, the active BIM system can provide decision-making functions to project manager and it can help to improve field applicability of BIM. This study introduces a concept of active BIM and a methodology for configuring the active 4D CAD functions. The applicability of suggested active functions is verified by a 4D CAD engine that was developed in the study. The developed engine has specialized active 4D functions for civil engineering works that consist of horizontal work area and bridges.

Keywords: 4D CAD, Active BIM, Passive BIM, Schedule Management, Optimization

1. INTRODUCTION

Most BIM (Building Information Modeling) systems used today are passive systems that focus on providing visual information during the design and construction phases of projects. In a passive BIM system, the areas of interference with the final design can be visually inspected with 3D objects, but it becomes difficult to propose additional solutions to the interference zone. Also, expressing the construction phase through each phase of the schedule using 4D simulation, although possible, is insufficient in terms of offering optimized scheduling plans that factor in the project's process conditions.

With recent applications of BIM in numerous organizations, the user requirement standards of BIM have surpassed simple visual information representation and have been developed into requests for active BIM, which can take identified problems and express solution methods with BIM. That is, active BIM provides the visualized status of each problems for the design and construction phases, and then it provides optimal solutions to solve the problems based on 3D object. This paper, in an effort to apply the concepts of active BIM, takes a 4D CAD system as an example, presents the capabilities of active BIM, and attempts to create an independently developed engine.

2. DEVELOPMENT TRENDS OF 4D CAD SYSTEM

BIM-related research is in progress in various forms around the world. As this paper's focus is on 4D CAD, precedents of 4D CAD operation systems research from both domestic and international institutions are reviewed. Kang et al(2013) presented a methodology for 4D CAD operations specialized for civil engineering works and an example of system development. Along with such findings, Kang et al(2010) also developed 4D CAD systems to make use of life-cycle simulation information of road construction.

To increase the practical applicability of 4D CAD, Ashwin et al(2010) examined examples of 4D CAD applications using quantitative and statistical analyses and proved the usefulness of 4D CAD. Timo et al(2008) took past precedents of 3D/4D model applications, sorted and analyzed them to present a plan to apply 4D CAD practically and efficiently. Russell et al(2009) developed a 4D CAD system that effectively performed construction management tasks while taking into account the linear scheduling of skyscraper construction.

The previous precedents in 4D CAD research were projects dedicated to improving the simulation methodology and centered on application examples. For 3D based workspace generation, research has been presented on standardized 3D based workspace generation. Additionally, there have been numerous examples of applying process optimization to genetic algorithms.

These preexisting precedents are all research that relate to simulation or spatial interference identification. This paper suggests an additional stage after the passive process of interference identification that can create an optimized schedule plan based on the construction schedule and interference minimization analysis, which in turn presents a methodology to effectively use active tools in optimal decision making of 4D objects.

3. BIM APPLICATION FOR BUILDING WORK AND CIVIL ENGINEERING WORK

Building works normally progress in a vertical direction, mostly being composed of repetitive tasks within a small area. On the other hand, civil engineering works are horizontal by nature, requiring non-repetitive tasks over a large workspace. These characteristics are the reason that BIM is comparatively used less in civil engineering works. In addition, large scale civil engineering works require a great deal of earthwork, which is difficult to express in three dimensions. Figure 1 compares the 3D forms of building work and civil engineering work.

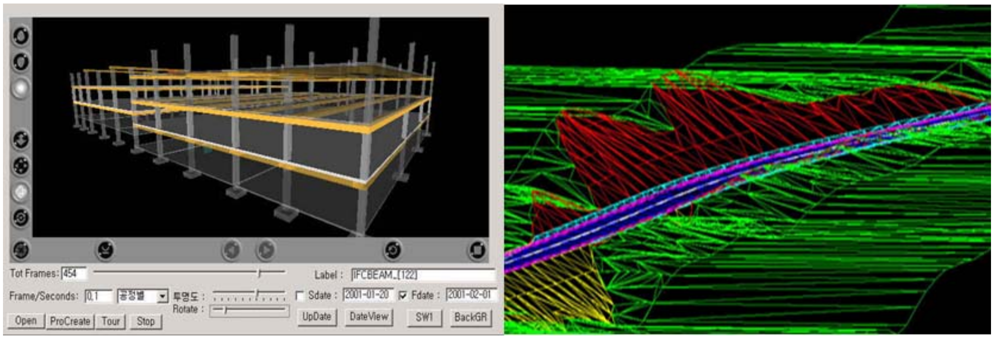

Figure 1: 3D object comparison between building work and civil engineering work

While the design phase carries more weight in building works, the construction phase is much more important in civil engineering works. As a result, 3D modeling and interference management during the design phase using BIM is crucial for building works, while using BIM for scheduling and constructability analysis is much more important in civil engineering works. In other words, BIM applications in civil engineering works can be much more easily found than in 4D, nD CAD construction management functions. For these reasons, BIM is used for 3D-based material estimation and 4D CAD schedule management than 3D interference management.

Although in comparison applying BIM to civil engineering works is more difficult than for building works, the need for BIM, from a schedule management perspective, is increasingly evident. Building works mostly consist of repetitive activities, making precedence and successive activities predictable. However, civil engineering works are mostly non-repetitive and facilities with identical functions may be composed of different parts or modules. Using the road construction project in Figure 2, paving, earthwork, bridging, and tunneling are all completely dissimilar forms of activities, and even within the process of bridge-building, hundreds of different activities exist. Such varied classifications make the prediction of precedence and successive activities difficult. Hence, compared to building works, pre-simulation functions through 4D CAD is ever more vital.

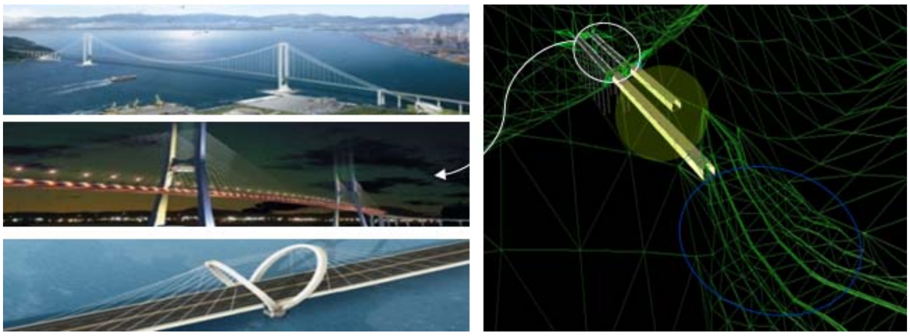

Figure 2: 3D models of each facility in road construction

If the earthwork for a structure's foundation is at the level of excavation, the earthwork required for a civil engineering work is a large-scale endeavor that transforms the terrain of the vicinity of the project. Such earthwork, to be represented in 3D, must be dealt with using irregular triangulate coordinates, which is technically challenging. It is also difficult to predict beforehand the final finished form of the earthwork, as errors are large between design phase and construction phase. Hence, visual management with BIM is necessary. Especially as civil engineering works encompass an extremely large area, compared to building works that takes place in smaller areas, using BIM to keep track of various joint construction information has become more and more vital. As a direct consequence, recent civil engineering works have increasingly pursued BIM.

4. APPLICATION OF ACTIVE BIM

4.1. Concept of Active BIM

Though current BIM tools offer the convenience of visualizing construction information, they focus on visualizing an interference situation or simple simulation for the design and construction phases. Hence the problem is outside of visualizing the areas required, and there does not exist a decision-making function that can help to solve issues with the visualized area. Recently, various organizations and projects have expanded their application of BIM, and are now requesting additional problem solving functions.

Because the passive BIM is generally focused on the simple visualization function that highlights possible problematic situations during the design and construction phases, BIM is being used with restricted functions. Conversely, active BIM is a system that can visually recognize any problematic situations and then use problem-solving methodology to visually represent an improved situation. In short, active BIM can offer decision making functions to inexperienced project managers without professional experience.

4.2. Passive and Active BIM in Design and Construction Phases

The typical BIM tool used at the design phase is the 3D-based interference management system. Though interference can still be found and represented as a 3D form using a passive BIM, it lacks the ability to go a step further and give information on the next phase of the solution process. Active BIM takes this extra step and modifies the original plan by rearranging certain parts of the model to eliminate interference or rescheduling the construction schedule.

During the construction phase, the 4D CAD system is an useful BIM tool. Though the existing passive 4D CAD systems can visually simulate the finished appearances of each facility by their construction schedules, it cannot give extra information for the purposes of construction management. For example, if the project schedule has much overlapping in the planned schedule, the project may have low constructability. In that case, current 4D CAD systems can only visualize the overlapping status using 4D object. An active 4D CAD system, however, can visually confirm the statuses of each overlapping activity, and then simulate a comprehensive schedule that minimizes the overlapping schedules within same construction duration. That is one of an active function that can be helpful for project manager. By minimizing such overlapping areas without changing the total construction time, the overall improvements in scheduling can be confirmed visually, introducing a new dimension in possible decisions. Figure 3 shows the development progress of a 4D object between passive BIM and active BIM concepts.

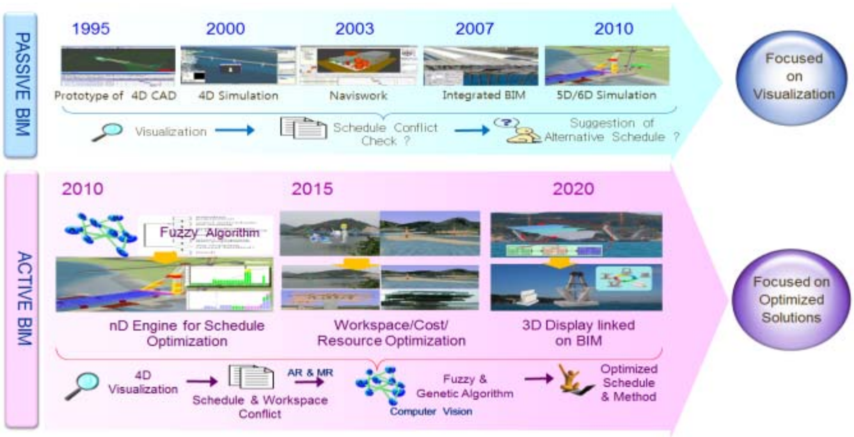

Figure 3: Evolution of BIM functions (4D object used as an example)

The upper portion of Figure 3 shows the development of passive BIM functions that place a greater emphasis on providing visual information. The bottom of the figure is a development roadmap of active BIM functions that can provide an improved solution using an optimization methodology to solve problems with the construction. To progress from passive to active BIM, many different methodologies may be applied to improve construction situations.

If project manager takes the earthwork task during construction phase as an example, passive BIM can create a 3D model of the excavated earth, but active BIM can use a path-search algorithm to find the shortest transport paths between the excavation sites and simulate an optimal earthwork plan.

4.3. Active 4D CAD Functions

Active 4D CAD system has all the original functions possessed by the current passive system, but also contains functions that can help with decision making. The various functions of active BIM can be seen in Figure 4.

Figure 4: The composition of active 4D CAD functions

Active BIM that includes 4D CAD systems, aside from their original ability to provide visual information, can analyze construction danger zone maps, and minimize scheduling and workspace interference. Typically, 5D CAD is a simulation that includes the costs of construction schedules. However, there is a large margin between the annual actual construction cost and the initial annual budget; hence the costs assigned to one year must be modified based on construction plans. Figure 4 further explains that cost estimation functions that can optimize costs and compose an optimal schedule plan that approximates the actual allocated cost are essentially active BIM.

If these new functions are offered with BIM, they have the potential to become powerful construction management tools for inexperienced project managers. Active BIM should also be able to present optimized task schedules by minimizing construction period overlap and spatial interference.

4.4. Process Optimization with BIM

Figure 5 is a representation of a schedule network optimization process that is simulated using a genetic algorithm. To analyze the danger level associated to each activity, the fuzzy analysis method is used to simulate tasks based on their danger levels using different colors. In order to perform schedule overlap optimization, a selection process that differentiates the schedules that have interfering parts within the original schedule is required. The selected activities are moved within float time and the changes are simulated such that interfering portions are minimized.

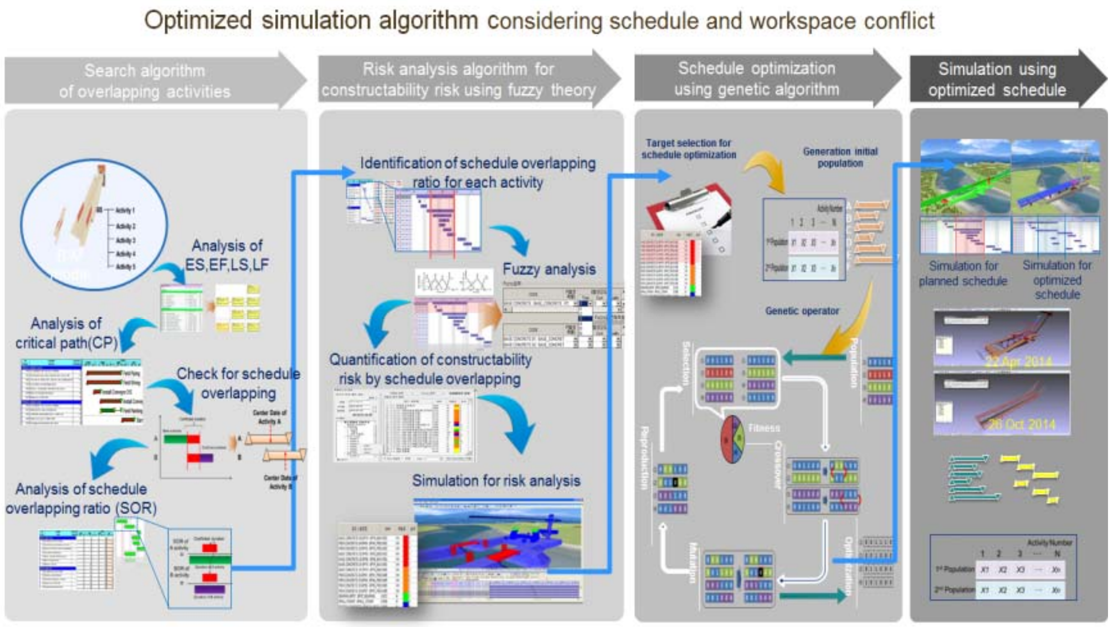

Figure 5: Application process of active BIM

As seen in Figure 5, active 4D CAD minimizes the schedule overlap between activities within a schedule network, and then the new schedules are compared with the original.

4.4.1. Schedule Overlap Minimization Simulation

If the project's total construction time remains unchanged, it is desirable to minimize the task scheduling overlap between processes. A project manager with active BIM can visually decide between numerous overlap minimized schedules. This can be seen in action through Figure 6. The two diagrams to the left and right of Figure 6 are the improved schedules after optimization simulations have been carried out.

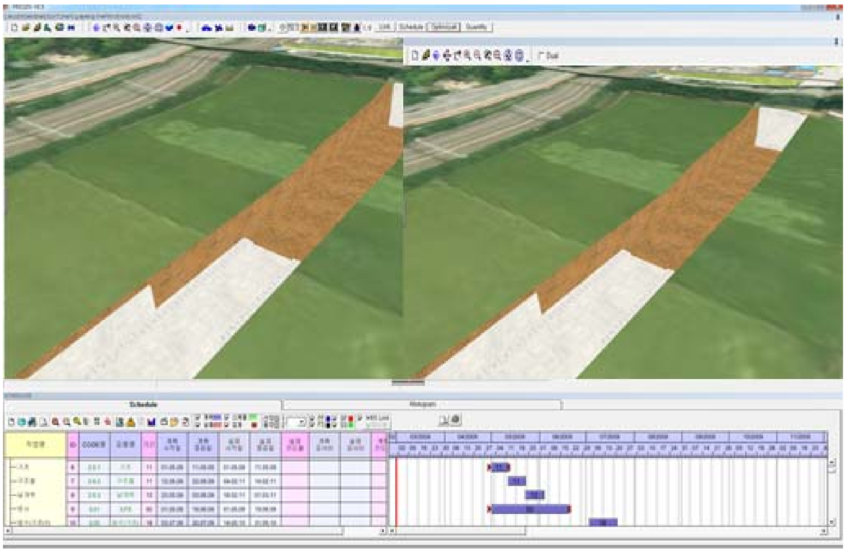

Figure 6: Active 4D CAD system (e.g. minimizing schedule overlap)

4.4.2. Task Area Overlap Minimization Simulation

One of the elements that needs to be considered in schedule management is the overlap between similar activities' task area. If similar activities have overlapping task areas, construct ability feasibility will decrease, and thus project managers should ensure that task areas do not intersect while keeping the total construction period the same. Such functions are a part of 4D CAD systems. To ascertain the overlap between task areas, a 3-dimensional space coordinate intersect evaluation method is calculated within the system. The task area used in this paper is uniformly rectangular, though area generation should be remedied depending on the activity types. Figure 7 is an example of work space overlap minimization through a active 4D CAD system. The project used in the example is identical to that used in Figure 6.

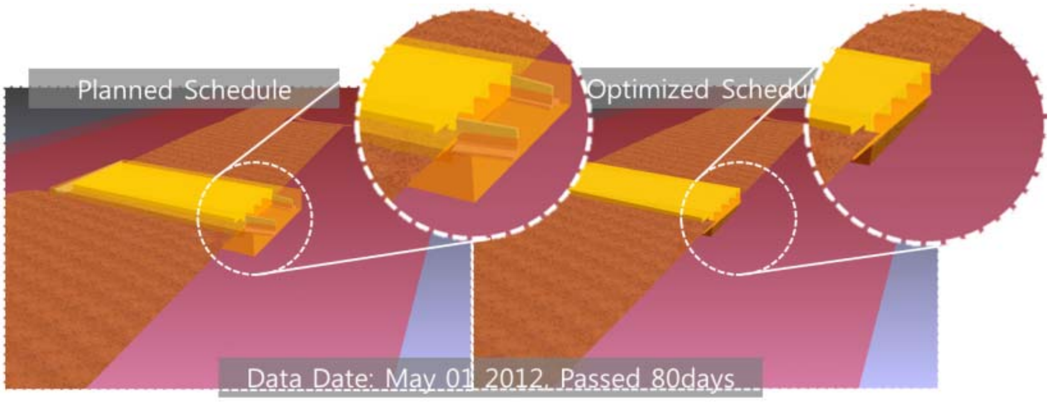

Figure 7: Active 4D CAD system (e.g. minimizing workspace overlap)

Within Figure 7, the diagram on the left is the initial schedule with work space overlaps simulated. The diagram opposite it shows the minimized workspace overlap simulation results where activities were moved within float time. In short, project managers can compare 4D representations of the initial and modified schedules to plan the most optimized process.

6. CONCLUSION

The basis of BIM application is to take information generated over a construction lifecycle and use it in a 3D framework. For BIM application to become more widespread, 3D object applied task process improvement and evolution of BIM that allows for 3D and nD objects to be used as decision making tools are necessary.

The characteristics of building works and civil engineering works were analyzed, and applying BIM used mostly in building works to civil engineering works was presented. BIM systems for civil engineering works need to be equipped with specialized functions such as horizontal simulation and detailed earthwork simulation for visualizing natural triangulate network coordinates.

A concept of a technically improved active BIM that can expand practical applications of BIM was presented in the study. A new engine that can analyze using genetic algorithms with 4D objects was developed and used on a case project to determine the usefulness of active BIM. The possibilities offered by an active BIM were confirmed through the methodologies and systems developed in this study. And the necessity of improving the current 4D CAD systems from passive function to active function was presented. To this end, a possible use for active BIM was reviewed using schedule overlap and workspace interference minimization as examples.

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A FUZZY MODEL TO DETERMINE CONSTRUCTION FIRMS' STRATEGIES

A. Kazaz
Akdeniz University, Antalya, Turkey, akazaz@akdeniz.edu.tr

M. T. Birgonul
Middle East Technical University, Ankara, Turkey, birgonul@metu.edu.tr

B. Er
Akdeniz University, Antalya, Turkey, bayramer@akdeniz.edu.tr

S. Ulubeyli
Bulent Ecevit University, Zonguldak, Turkey, serdar.ulubeyli@karaelmas.edu.tr

Abstract

This paper presents a study that intends to develop a fuzzy logic model to determine construction firms' strategies. Toward this aim, 50 large-scale construction firms in Turkey were interviewed to reveal their current positions in terms of "Strengths, Weaknesses, Opportunities, and Threats" (SWOT), and to identify their primary goals. As a result, a high correlation was observed between the SWOT analysis and primary goals. Then, a fuzzy logic model was developed based on the results of the SWOT analysis. This model was tested by each firm's data, and a success ratio of 98% was gained in total.

Keywords: fuzzy logic, Miles and Snow typology, strategy, strategic management, SWOT analysis.

1. INTRODUCTION

The construction industry is related with many sub-sectors and includes different trades. In this regard, many construction companies offer different professional services that have a number of specialties. In the era of increasing globalization, the number of national and international contracting activities rises and the industry become more complex in time. This diversification and complexity naturally increase uncertainties and risks in construction. The industry is also very sensitive to internal and external drivers such as capital, experience, technology, economy, politics, etc. These factors may influence companies in a positive or negative manner (Danosh, 2005). Therefore, construction firms should properly determine their roadmaps and the corresponding strategies. In this context, top managers should correctly evaluate strengths/weaknesses of their firms and opportunities/threats of the market.

Before determining a strategy, firms should specify their goals, comprehend internal and external factors, and thus identify clear advantages. In other words, it is expected that there is a high correlation between goals and strategies of firms. As a result, the applicability of strategies depends on how much suitable the goals are in terms of firms' organizational structures and the overall environment. Hence, firms have to evaluate themselves and their current positions in the market to choose the right strategies.

Although construction firms do not pay the required attention to the strategic management domain (Cheah et al., 2004), in the last two decades it has become widespread among large-scale construction firms to assign more resources to strategic thinking (Price et al., 2003). The main reason behind why construction firms neglect strategic management is that the top managers mainly focuses on the execution of construction projects instead of managing daily operations (Chinowsky and Meredith, 2000; Danosh, 2005).

Although many construction firms neglect to apply a formal strategic management process, this does not mean that they do not follow any informal strategic way. In fact, strategic management is not utilized in a formal manner among most of construction firms. The fact that firms without strategic management are still operating in their markets confirms that they have achieved their goals. Therefore, introducing a new methodology to select proper strategies will help firms to easily adapt a strategic management process. In this context, a model was developed by using the fuzzy logic approach to help construction firms in choosing suitable goals and strategies. A research of three stages was carried out. In the first phase, data for the model was compiled by means of a questionnaire survey. In the second phase, a fuzzy model was developed based on the data to determine construction firms' main goals. Finally, proper strategies for each goal were proposed in a detailed manner.

2. RESEARCH METHODOLOGY

In this study, it was investigated whether there is a high correlation between the firms' organizational structures/current positions in the market and their main goals. For the first part of the survey, questions on a SWOT analysis was prepared to evaluate internal and external factors. Although SWOT analysis has been utilized in many studies so far, its content changes with the industry and the market. Given that external factors changes by region, for an effective SWOT analysis region-specific opportunities and threats should be identified. However, in general terms, by developing a SWOT analysis, (i) internal factors such as management ability, financing ability, marketing skills, labor capacity, experience, etc., and (ii) external factors such as politics, economics, market size, etc., should be taken into account. In this regard, SWOT analyses in the literature were examined and questions on a SWOT analysis for construction firms operating in the Turkish construction industry was prepared (Table 1). These factors were organized on a 5-point Likert-scale where 1 and 5 represented "absolutely disagree" and "absolutely agree", respectively.

In the second part of the questionnaire, the top managers were asked to choose one of the four goals: (1) customer satisfaction, (2) process optimization, (3) risk minimization, and (4) profit maximization. This part of the questionnaire was necessary to examine the correlation assumed above. Moreover, these four goals were also output variables of the fuzzy model.

Strengths	**Weaknesses**
Cheap material supply	Lack of experience
Compliance with the sector	Lack of financial solutions
Reliability in the sector	Lack of experience in complex projects
Qualified staff	Insufficient use of information technologies
Sufficiency of machine park	Lack of design and technical experience
Experienced managerial staff	Wrong choice of investments
Labor force	Hang back to specific targets
Benchmarking	Distance problems related with material supply
Political support	
Cheap labor force	
Financial capability	
Product quality	
Establishing joint venture	
Opportunities	**Threats**
Improvement of international construction market	Difficulties in getting permits
Openness to global construction market	Competitive environment of the global construction market
Having foreign partners	Operating in an industry that offers heavily integrated services
Receive progress payments on time	Competitive environment for qualified staff
Nearness to developing countries	Firms with low manufacturing costs
Increase of demand in domestic market	Economic uncertainty
Free land allocation	Political uncertainty
Exemption from tax	Capital gain of currency
Incentive premium	Wars
Technological improvements	Economic crisis

Table 1: Factors of SWOT analysis

"Miles and Snow Typology" was used to identify these main goals. This typology is one of the widely used typologies in the literature (Ozdemir, 2012). It was first suggested in 1978 (Miles et al., 1978). They defined four different organization types with different strategies as follows:

– Defenders: These types of organizations can also be defined as conservative. The limited product range leads organizations to focus on internal competencies improvement instead of developing new products or entering new markets. They maintain a stable market segment (Desarbo et al., 2005). In the present study, it was assumed that such firms should have the following main goals to maintain or strengthen their positions in the market:

customer satisfaction to increase customer diversity, and process optimization to increase product quality.

– Prospectors: Unlike defenders, this kind of organizations has a broad product or market domain. Their environment is also more dynamic compared to other organizations within the same industry. They are always in search of new products or markets. Therefore, these firms are good at making use of opportunities. In this study, it was discussed that these firms are searching new markets because of two main reasons: (1) decrease in the profit margin due to competitive environment or shrinkage in the market size and (2) invest in more profitable markets. The notion behind these reasons is to increase profits. Thus, the main goal of firms should be the profit maximization.

– Analyzers: This type of organizations falls between defenders and prospectors. They are moderate in internal and external factors. In other words, they are weak in internal and external factors compared to "defenders" and "prospectors", respectively. In this regard, their main goal should be the risk minimization to survive in the market and to be defensive against threats in the market.

– Reactors: These organizations do not have a particular strategy and they just try to adjust themselves to short-term changes to survive in the industry (Desarbo et al., 2005). They have an inconsistent and unstable environment. This type of strategy is prominent when the aforementioned strategies are not properly followed. In fact, these are small-scale companies and were not considered in this study.

To increase the reliability of the fuzzy model, samples were composed of construction firms which were large-scale and have noteworthy experience in the Turkish construction industry. For this purpose, construction firms that are members of Turkish Contractors Association (TCA) were contacted. TCA is an independent and non-profit professional organization that has currently 152 members. The business volume of its members encompasses nearly 70% of all domestic and 90% of all international contracting work done so far by Turkish construction companies. In addition, nearly 75% of its members are active in various fields of tourism, manufacturing, and engineering.

50 firms (32.89%) positively responded to the survey request, which makes the sample size ($n=50$) statistically large ($n \geq 30$) enough for representing the whole. The questionnaire was administered face-to-face to respondents at their offices and all collected data were used in the statistical analysis.

3. RESULTS OF SWOT ANALYSIS

Test of Internal Consistency was used to test the reliability of the results of SWOT analyses. The Cronbach's alpha value was calculated as 0.891 which was in the accepted interval between 0.600 and 0.900. Similarly, consistency tests were also conducted for each sub-dimension (strengths, weaknesses, opportunities, and threats) of the analysis. The Cronbach's alpha values of each sub-dimension were 0.892, 0.747, 0.869, and 0.871, respectively. These confirmed that the results of SWOT analysis and its sub-dimensions are reliable.

The validity of the analysis was confirmed by exploratory factor analysis. This method was also used to reduce the number of input variables of the model. The Kaiser-Meyer-Olkin test and the Bartlett test of sphericity are preliminary tests employed to evaluate the suitability of data for factor analysis. The results of these tests (Kaiser-Meyer-Olkin = 0.637 and p = 0.000) showed that the data were appropriate for factor analysis.

After the factor analysis, three factor groups (competency, opportunity, and threat) were extracted contrary to expectations of four factor groups. This is because the opposite pattern resulted in a high correlation between questions related with strengths and weaknesses. Hence, they were grouped under the same factor. Competency refers to strengths and weaknesses, opportunity refers to making use of opportunities, and threat refers to the degree of being affected from threats. These three factors account for 62.78 % of the variance.

4. STRATEGY GROUPS OF THE FIRMS

The firms were first grouped according to their main goals, and the results of SWOT analysis were examined individually to determine their strategy groups. After investigating results of the questionnaire, three different firm profiles were fixed (Table 2).

Miles & Snows' Strategy Typology	Features	Goals
Defenders (Type 1)	strong compared to their competitors leery in making use of opportunities	process optimization customer satisfaction
Prospectors (Type 2)	moderate strong good at making use of new opportunities	profit maximization
Analyzers (Type 3)	weak compared to their competitors close to improvements very defensive against threats	risk minimization

Table 2: Strategic profiles of the surveyed construction firms

5. MODEL DEVELOPMENT

After Zadeh (1965) introduced fuzzy sets in 1965, fuzzy techniques have been widely utilized in many research areas in past decades. Fuzzy logic has its strength in connecting humans with computers (Chan et al., 2009) by assessing linguistic statements with numerical values. This ability allows model handling some concepts that are meaningful but cannot be clearly defined (Elbeltagi et al., 2012). In this study, fuzzy logic was utilized for decision making and modeling. A system that contains three inputs and one output was used.

5.1 Input variables

Numerous input variables complicate the fuzzy model development because it increases the number of fuzzy rules. It becomes difficult to extract an answer for each rule. Therefore, it is recommended to reduce the number of input variables by using the most dominant ones. In this study, instead of using dominant factors and neglecting the remaining, a factor analysis was conducted. As a result, factors that have high correlation were grouped under three factors (competency, opportunity, and threat) and used as input variables. Thus, all factors were considered during the model development and none of them were neglected.

5.2 Output variables

Main goals asked in the questionnaire were the output variables of the model. Accordingly, the membership function included four fuzzy sets. The model was developed for classification purpose and each fuzzy set was independent from each other. There was neither an intersection between the sets nor a sequential increase or decrease of them. Since the purpose was classification, Mean of Maximum (MOM) defuzzification method which extracts the output with the highest probability was used (Ozdemir, 2012).

5.3 Fuzzy rules

The last step of model development was to establish the rules. Fuzzy rules were the conditional statements of the model. These rules decided which output would be extracted under certain conditions. In other words, they showed the correlation between inputs and outputs. In this study, three membership functions, each with three fuzzy sets, were used, which was resulted in 27 (3^3) rules. The necessary experience needed for identifying the rules were gained after examining the SWOT analysis results of each construction firm.

6. MODEL VALIDATION

To validate the model, each firm's data were specifically tested and model results were compared with the actual ones. Only four firms' actual goals were different from the ones extracted from the model. According to this result, the success ratio was 98% which confirmed the validity of the model.

To better understand the working principle of the model, a case study was explained and illustrated. The results of SWOT analysis of a randomly selected firm are 58% for opportunity, 91.5% for competency, and 54% for threats, and its primary goal was identified as customer satisfaction. After entering these data to the model, the probabilities were 0.58 for customer satisfaction, 0.17 for process optimization, and 0.02 for risk minimization. According to MOM, the goal with the highest probability (that is, customer satisfaction) would be extracted as the output of the model as shown in Figure 1.

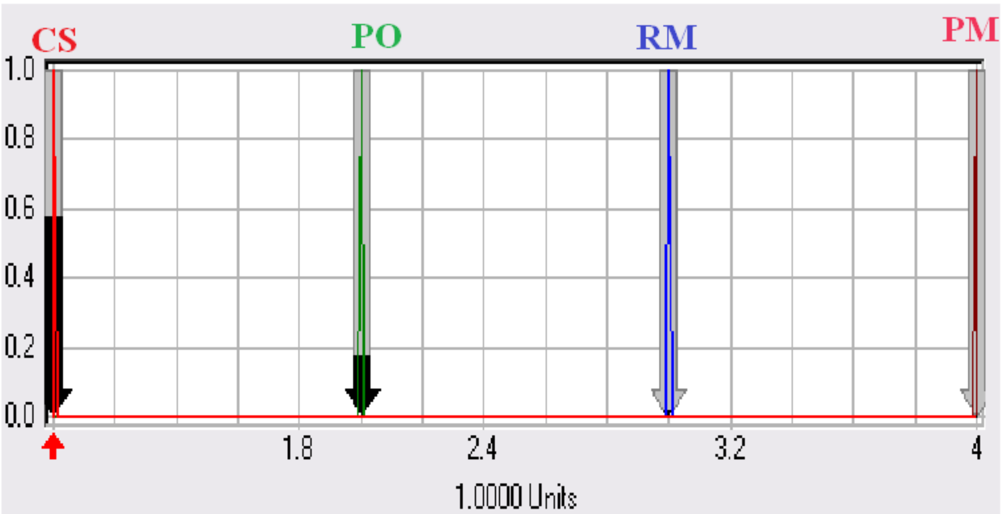

Figure 1: Model output of the case study

7. STRATEGY DEVELOPMENT

The last step of this research was to develop proper strategies related with the identified main goals of the firms. In this regard, results of the research until this stage were e-mailed to the respondents and they were asked to propose some specific strategies. Only 36 respondents participated to this part of the study. The others refused because they were not willing to share their firm's specific strategies. As a result, several strategies were developed for each goal based on the top managers' proposals (Table 3).

Goals		Strategies
Goals	Customer Satisfaction	Developing a Total Quality Management System
		Select projects appropriate to the firm's capacity and profession
		Developing Risk Management System
		Giving advertisements to mass media
		Constructing projects as donation
		Donating to charities
		Awarding scholarships to students
	Process Optimization	Focusing on project management
		Keeping track of new technology
		Developing new technologies
		Constituting a Research and Development department
		Determining alternative material suppliers
		Determining alternative subcontractors
	Risk Minimization	Changing the firm's strategy group
		Developing Risk Management System
		Utilizing an effective contract management
		Determining reliable subcontractors
		Determining reliable construction firms for joint venture establishment
	Profit Maximization	Increasing project types that firm could give proposals
		Increasing the firm's labor and machine force
		Determining appropriate services that are close to their professions
		Offering services that are outsourced
		Exploring new markets

Table 3: Strategies for each goal

8. CONCLUSIONS

The construction industry is very sensitive to dynamic environment. Any change of environment may affect firms positively or negatively. Moreover, the industry is also highly competitive. Therefore, it is vital for firms to identify appropriate strategies to cope with or take advantage of these changes. Although construction firms achieve their objectives to some extent and survive in the market, many studies revealed that a formal strategic management process is not popular among construction firms.

In this study, it was intended to develop a methodology that will help construction firms to select appropriate strategies for their organizations. For this purpose, a survey including questions on a SWOT analysis was administered to top managers of 50 large-scale construction firms in Turkey to evaluate them. In addition, these top managers were also asked to choose one of the given goals as their firms' main goals. After the necessary experience was gained in the first part, a fuzzy model was developed for determining the firms' main goals. Finally, relevant strategies in accordance with the firms' main goals were introduced.

Although this study was conducted in Turkey, the methodology can also be utilized in different countries by appropriately changing the SWOT analysis content and developing a new model. Overall, applying this methodological procedure can facilitate the adaption of the strategic management process in the construction industry.

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MINIMIZING CONSTRUCTION ACCIDENTS USING CARTOONS IN HEALTH AND SAFETY TRAININGS

Serkan Kivrak
Anadolu University, Faculty of Engineering, Civil Engineering Department, Eskisehir, Turkey, serkankivrak@anadolu.edu.tr

Serdar Ulubeyli
Bulent Ecevit University, Faculty of Engineering, Civil Engineering Department, Zonguldak, Turkey, serdar.ulubeyli@karaelmas.edu.tr

Salih Serkan Artagan
Anadolu University, Faculty of Engineering, Civil Engineering Department, Eskisehir, Turkey, ssartagan@anadolu.edu.tr

Volkan Arslan
Bulent Ecevit University, Faculty of Engineering, Civil Engineering Department, Zonguldak, Turkey, volkan.arslan@hotmail.com

Abstract

The construction industry has always been regarded as one of the least credible sectors in terms of construction accidents. It has a poor safety record compared to other industries. Construction accidents do not only cause human tragedy and economic losses, but also they lead to inefficient productivity and a notorious prestige about the sector. Lack of proper training and knowledge about health and safety issues are some of the main causes of construction accidents. Lack of training can be attributed to insufficient safety and health management by the construction companies. Thus, an effective training program implemented by the companies has a great potential to minimize these accidents. This paper gives an insight of a study aiming to prepare cartoons emphasizing construction accidents and the reasons behind them. By utilizing the sense of humor which is global, these cartoons can be used as learning materials in health and safety trainings in construction industries to minimize accidents. The majority of health and safety trainings given to construction workers consist of theoretical trainings. Since the majority of the construction workers have a low education level, learning the health and safety concepts with theoretical trainings are quite difficult for these workers. Therefore, cartoons that have the potential to make trainings more attractive and enjoyable with addition of humor and the visuality, can overcome this problem. In this study, the potential effects of using cartoons on health and safety trainings in construction will be examined.

Keywords: Cartoons, Construction Accidents, Construction Industry, Health and Safety Trainings.

1. INTRODUCTION

Construction industry has been one of the most dangerous industries in terms of health and safety risks inherent in it (Carter and Smith, 2001). It has a poor safety record compared to other industries. Risk of a fatality incidence in the construction industry is five times more likely than in a manufacturing-based industry (Davis and Tomasin, 1990). Toole (2002) listed the main causes of construction accidents as lack of proper training, deficient enforcement of safety, lack of safety equipment, unsafe methods or sequencing, unsafe site conditions, not using provided personal safety equipments, poor attitude toward safety, and isolated, sudden deviation from prescribed behavior.

According to Langford et al. (2000), five factors which mostly impact the safety attitudes of workers in the construction industry are found as organizational policy, supervision and equipment management, industry norms, risk taking and management behavior. However, awareness of health and safety in the construction industry has yet to occur completely and most of the employers and employees involved in the industry exhibit insensitive attitude towards this subject (Kazaz, 2009).

Particularly, in the developing countries, insufficiency of the health and safety applications is one of the frequently emphasized subjects by the researchers (Kheni et al., 2008). The number of accidents in terms of some selected industries in Turkey is demonstrated in Table 1 (Turkish Ministry of Labor and Social Security, 2007). As seen from this table, the construction industry has the highest number of fatal accidents in Turkey.

Industry	Number of Accidents	Number of Occupational Illnesses	Number of Fatal Accidents
Mining	6589	997	45
Construction	7615	16	359
Food	2438	6	30
Metal Products	17147	61	60
Transportation	4483	13	146
Machinery Manufacturing	5497	10	19

Table 1 Number of accidents according to industries in Turkey (2007)

It has been also indicated that the most significant factor in construction site accidents is the unsafe behavior. Researches reveal that accidents causing death stem from falls, struck-by accidents, caught in /between incidents and electrocutions. (Dester and Blockley, 1995; Sawacha et al., 1999).

Construction accidents do not only cause human tragedy and huge economic losses, but also they lead to inefficient productivity and a notorious prestige about the sector. (Kartam, 1997). Everett and Frank (1996) determined that in construction projects of buildings which are excluding housing projects, accidents account for from 7.9 % to 15 % of the total cost of those buildings. Coble and Hinze (2000) stated that the total compensation costs of the workers sum up to 3,5 % of the total project cost. Moreover, as a result of a study including 15 European Union countries, 6 % of the total construction turnover is spent for the expenses related to occupational accidents and illnesses (HSE, 1997). Hinze et al. (2006) examined 136,000 injury cases of construction workers. They tried to present the impact of the slight injuries upon the cost. According to their results, more than half of the injuries are cuts. Tang et al (2004), worked on the cost of the accidents and concluded that each 1 US Dollar investment in health and safety applications will save 2.27 US Dollars. Demoralized workers, delayed project delivery dates, and damaged equipments can be given as examples.

In the study of Arslan and Kivrak (2009), lack of safety training was found as one of the important factors that can cause construction accidents in Turkey. One of the most important results of the study of Arslan and Kivrak (2009) was the significant relation between health and safety trainings and accident rates. Larsson et al. (2008) emphasized that if favorable environment and individual climate for the workers are provided by the managers, safety behaviors of those workers improve. It is stated that key point to safety lies within the management (Larsson et al., 2008). Lack of training can be attributed to poor safety and health management by the companies. Thus, an effective training program implemented by the companies has a great potential to minimize these accidents.

2. HEALTH AND SAFETY TRAININGS IN CONSTRUCTION

In preventing possible accidents in construction sites, Health and safety training programs can provide several advantages The significance of safety training for the safety performance in the construction industry has been emphasized by many researchers (Huang and Hinze, 2003; Aksorn and Hadikusumo, 2008). Effective training of construction workers can be one of the best ways in improving site safety performance (Hislop, 1991; Tam et al., 2004). Zeng et al. (2008) indicated that it some accidents such as falling from height and hit by falling materials in construction can easily be prevented by applying efficient training programs. In the same study, it has also been found that many workers in the Chinese construction industry had received restricted education about safety issues (Zeng et al., 2008). Similarly, Dingsdag et al. (2008) stated that construction workers identified training as a necessary element of safety performance.

Many studies have shown that there is a close relationship between individual safety behavior and safety performance (Tarrants, 1980; Sawacha et al., 1999). Effective training of workers can also significantly reduce unsafe behaviors. As Fang et al. (2006) stated, workers with good safety knowledge have a more positive safety climate than those with poor safety knowledge. On the other hand, Mohamed (2002) found a significant relationship between the safety climate and safe work behavior. He stated that safe work behaviours are consequences of the existing safety climate. Safety climate is 'a summary concept describing the employees' beliefs about all the safety issues (Guldenmund, 2000). Varonen and Mattila (2000) determined that ratios of accidents and injuries are less in the construction companies having a culture of health and safety than the ones which do not possess that culture after a research involving more than 500 people exceeding 3 year period. Mohammed (2002) expresses that employee's attitude towards health and safety is dependent on the support in health and safety issues given by the construction companies. Langford et al. (2000) identified the critical factors that influence the attitudes of construction workers towards safe behavior on construction sites. According to the results of their study, training of operatives and safety supervisors are important to safety awareness and improved performance. Moreover, it has also been found that knowledge and competence influence personal safety performance. They also stated that companies must maintain and update their workers' skills and knowledge by training, skill updates and effective on-site communication (Langford et al., 2000).

In addition to minimization of construction accidents, successful training can also minimize project delays and damage to company image (Findley et al., 2004). On the other hand, lack of safety training of construction workers has been considered as one of the important causes of construction accidents (Gervais, 2003). As mentioned before, construction industry is the most risky sector for industrial accidents and occupational illnesses all over the world. However, health and safety culture has not been established yet by many construction companies. Many researchers demonstrate that, especially in developing countries labor safety applications are insufficient. In Turkey, most of the construction projects are constructed by small or medium-size construction companies. In the majority of the firms there is a lack of safety culture. Moreover, the education level of workers is low and the majority of these workers have no safety training in the past. All these conditions increase the number of accidents. To prevent the accidents, labors must be well educated about safety.

Consequently, effective safety trainings are critical for improving safety performance in the construction industry. There is a significant relation between health and safety trainings and accident rates. However, the majority of health and safety trainings given to construction workers consist of theoretical trainings. Construction workers generally have a low education level, therefore learning the health and safety concepts with theoretical trainings are quite difficult for these workers. Using cartoons by using the global sense of humor in health and safety trainings can be an effective method to overcome this problem and improve the safety performance in this industry.

3. HEALTH AND SAFETY TRAININGS USING CARTOONS

As Ozdis (2010) stated by referring to Bremmer (1997), humor is regarded as the key of the cultural codes and past sensibilities. Humor when used appropriately has the potential to create a learning environment and keep people thinking (Torok et al., 2010). Cartoons which are the visual scenes for humor can be used as an efficient training tool in health and safety management in the construction industry. In addition to humor, cartoons also carry a stunning, striking and recollective visual aspect. An effective cartoon may display construction accidents, reason and/or the consequences of construction accidents. Such cartoons viewed by the target group i.e. construction workers will help them acquire thematic sense reflected in the cartoon to an extent which will enable him or her to direct his/her focus to health and safety aspects in construction by keeping in mind the funny and/or dramatic flashbacks from such cartoons.

Here an overview and the preliminary stages of an ongoing project which aims to prepare cartoons displaying construction accidents and emphasizing the significance of health and safety are presented. These cartoons can be used as learning materials in health and safety trainings in construction companies to improve the trainings of the staff by adding humor and visuality and therefore avoid or minimize accidents.

In the first step of the project, the current conditions of health and safety in construction industry in Turkey will be analyzed. The main causes of accidents, yearly accident statistics and the most frequently happened accidents in construction industry in Turkey will be determined using the statistical data from the Turkish Statistical Institute. The findings from the first step will be a basis for the second stage which is related about categorization of occurrence frequency of real accidents.

The second stage of the project consists of the preparation of cartoons based on the categorization. The accidents will be grouped according to their frequency as; the most frequently, frequently and rarely occurring accidents. Furthermore, they will also be grouped according to their severity as; fatal, severe injury, and minor injury accidents. These groupings will be based on the data that will be obtained in the first stage. The main aim of this stage is to prepare effective cartoons that will exhibit construction accidents, reason and/or the consequences of construction accidents. In the cartoons, the definition of construction accidents, their frequency, place, severity, the cause and consequences of accidents, and the possible precautions to prevent these accidents will be explained. Designing cartoons is the most important stage since it is the innovative part of the project. The learning materials for health and safety trainings will be created at this stage. In this stage, construction accident cartoons will be prepared based on the real cases. Within the project, cartoons will be prepared according to high frequency, low frequency and seldom occurring accidents. Moreover, the cartoons will be categorized according to work types such as formwork, reinforcement, concrete and excavation. Table 2 illustrates some examples of these work types. The main purpose of categorizing the cartoons according to the work types is to create learning materials for specific trainings such as 'work at height' etc,. These groupings can help to provide effective training materials to the workers working in such areas.

Cartoons		
Electrical	Masonry	Loud sound works
Plumbery	Plastering	Excavation
Transportation	Reinforcement	Heat and water insulation
Painting	Highway construction	Doors & Windows
Welding	Concrete	Hazardous materials
Soil	Machine-Equipment	Formwork
Site safety	Roof	Scaffolding

Table 2 Examples of groupings of cartoons according to work types

For less educated employees, cartoons can have a great potential in achieving efficient results in health and safety trainings. Cartoons can make trainings more attractive and enjoyable. According to previous studies, 80% of human memory skills and learning are developed by visual learning. Therefore, cartoons can improve memory skills and provide an effective learning. Cartoons do not contain any spoken dialogue. Messages could be understood from images and limited wording.

Some views of the sample cartoons prepared for this project are shown in Figures 1, 2 and 3.

Figure 1 A sample cartoon emphasizing the fatal results of construction accidents

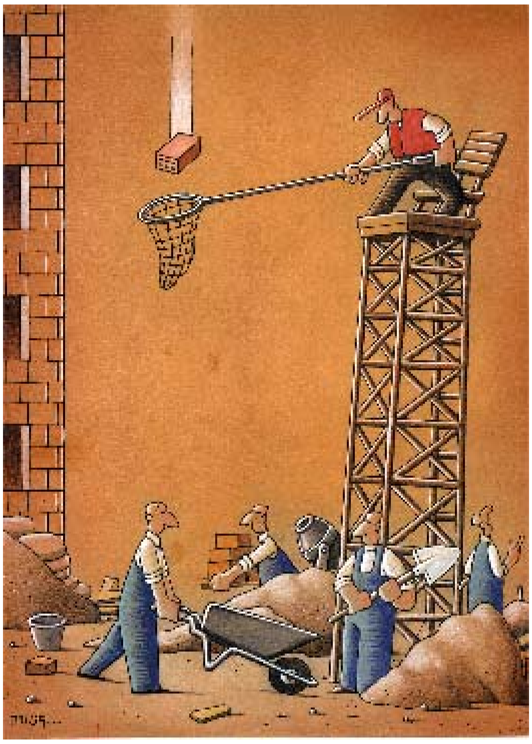

Figure 2 A sample cartoon emphasizing construction accidents

Figure 3 A sample cartoon emphasizing the fatal results of construction accidents

The next stage of the project is the application of health and safety trainings using these cartoons. The main objective of this stage is to test and evaluate the effectiveness of health and safety trainings using cartoons. For this purpose, the leading Turkish construction companies will provide technical support for this project. These trainings will be performed with Health and Safety Departments of these firms. Besides theoretical trainings, trainings with cartoons will be given at the construction sites of these companies. Using accident statistics, the effect of training with cartoons will be determined. To compare the results of the new method, accident rates will be compared with previous years using accident reports and accident data statistics. Thus the efficiency of these materials will be evaluated.

Methods used for comparing accident rates are; accident frequency, recurrence rate, number of accidents/ compensation payment per day rate of number of accidents/ number of worksite. Frequency of accidents method is the mostly used criteria for comparing different firms and sectors. Frequency of accident is the rate of accident for every thousand workers. ANOVA parametric test method will be applied in the analysis of the results. ANOVA examines the influence of variables to other variables. ANOVA is used to compare two or more groups and shows the differences between groups. Moreover, to determine the success of trainings with cartoons, the perceptions of construction workers about safety culture will be assessed by a survey questionnaire both before and after trainings. The analysis of the data collected from the surveys will be evaluated using paired sample t-test.

4. CONCLUSIONS

This paper presented an overview of the ongoing project which aims to prepare cartoons that show not only construction accidents but also the reasons and undesired consequences of construction accidents. These cartoons will be used as learning materials in health and safety trainings in construction industries to minimize accidents. The results of the project will be tested at construction sites and the effects of these trainings will be examined. In most of the countries, there is a vast need of effective health and safety training programs in construction sectors to reduce accidents. Therefore, a great impact is expected from this project.

Using cartoons will significantly facilitate learning about the health and safety issues in construction. Since now, although many significant improvements in health and safety trainings have been performed, there are still improvements needed to minimize accidents. Therefore, the training materials that will be established in this project will be very useful visual learning materials. The present project will strongly support the development of health and safety trainings in the construction industry. Moreover, in the future, the training materials can become an important visual material for health and safety courses in the universities as well.

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EX POST RISK ANALYSIS OF GREEK MOTORWAY CONCESSIONS IN DISTRESS

Sergios Lambropoulos
National Technical University of Athens, School of Civil Engineering, Athens, Greece
laser@central.ntua.gr

Marina Marinelli
Queen's University Belfast, School of Planning, Architecture and Civil Engineering, Belfast, UK
marinakmarinelli@yahoo.gr

John-Paris Pantouvakis
National Technical University of Athens, School of Civil Engineering, Athens, Greece
jpp@central.ntua.gr

Abstract

The current financial crisis in Greece had an almost catastrophic impact on four motorway concessions under construction. Following the dramatic decrease in the traffic volume and the substantial rise of market interest rates due to the country's investment risk increase, the lending banks have temporarily withheld construction financing. Consequently, all construction activities in the four concession projects have stopped since 2011. Prior to the financial crisis and stoppage, the projects had already faced long delays due to time-consuming expropriation procedures, archeological investigations and permit issuance. These delays had generated important claims by both the concessionaires and their constructors. In addition, groups of users had organized a refuse-to-pay movement which had reduced toll revenues and further undermined the concessions' long term financial equilibrium. The re-activation of these projects, with a total budget of € 7.6 billion, will contribute to the development of the stagnant economy and to the reduction of the high unemployment rate in Greece. In order to specify the necessary actions and additional funds which will allow this, lengthy negotiations are in progress among the State, the concessionaires, the lending banks and the European Commission. In this paper, the important risks, which were underestimated in the contracts and had traumatic consequences to projects' progress when realized, are analyzed and discussed ex post. For each particular problem, proper mitigation measures are proposed, including existing contractual clauses rectification, administrative measures introduction and law amendments. The lessons learned and the subsequent proposals made are expected to contribute to the increase of the financial viability and stability of future concession contracts.

Keywords: concessions, motorways, project financing, recession, risk.

1. INTRODUCTION

The Greek State tendered four motorway concession contracts in 2005 in order to finance, construct and operate sections of the Transport European Transport Network (TEN-T). All four concessions commenced in mid 2008 after lengthy procedures, including international procurement, ratification by the Greek Parliament in 2007 and financial closing. At that time, public procurement of infrastructure concessions was booming worldwide.

During the current financial crisis in Greece, the traffic volume decreased dramatically, since it depends heavily on the performance of the economy and the users' reaction. In addition, the market interest rates rose considerably due to the substantial increase of the country's investment risk. The first signs of the concession contracts financial instability started to appear by the end of 2010. A refuse-to-pay movement, organized by groups of users, had further reduced the toll revenues. Furthermore, the international financial and credit crisis caused disturbances in the operation of many lending institutions, both Greek and foreign. The Lenders had been bound to finance the projects with low interest rate margins, compared to the rates currently available to the Greek State in the capital market. They were also concerned that the Greek State would not be able, in the middle of the crisis, to honor its obligations deriving from the concession contracts. In order to re-evaluate the long term viability of the concessions, the Lending Banks requested from the State and the Concessionaires to update the traffic and financial models. Adding to the uncertainty, accurate prediction of traffic volume during a transition period is an extremely difficult exercise; the further in the future the traffic forecast, the greater the inaccuracy. In parallel, the Lending Banks suspended the drawdown payments in all four contracts. As a result, all construction activities have been suspended since 2011.

The four concessions had already faced long delays prior to construction suspension. These delays had been generated due to time-consuming expropriation procedures, extended archaeological investigations, prolonged procedures for permit issuance etc. By the end of 2010, after the 50% of the total contractual construction period had elapsed, the progress of works on the three projects corresponded only to the 17%-24% of the scheduled progress, while on the fourth one this percentage was about 60%. Based on these delays, the Concessionaires and their Constructors raised high claims against the State.

The re-activation of these projects, with a total budget of € 7.6 billion, will accelerate the country's economic growth, lessen the reservations of the international markets regarding the country's investment risk, attract future investors and reduce the high unemployment rate in Greece. On the contrary, concessions failure may drive the country into a long disinvestment period and further rise of unemployment. In order to define the necessary actions and additional funds, lengthy negotiations are in progress among the State, the Concessionaires, the Lending Banks and the European Commission.

During recession times, the governments' appetite for new concessions increases; Public Private Partnership is considered as a reasonable means to keep investing in infrastructure with minimal impact on the State Budget deficit. In a period of financial instability, the private sector seeks opportunities to get long-term business from the State. On the other hand, during these periods the banks have limited funds available for lending; the same holds true for the private investors. The banks and the investors have become more prudent and ask for high loan interest rates and high return on equity. As a result, concession contracts are currently relatively scarce and more expensive for the client. In the light of the multitude of parameters influencing the economic life of projects, it becomes vital that the long term financial viability of the projects, in conjunction with the fair sharing of risk between the contractual parties, should be well established and clearly embedded in the contracts. This will contribute substantially to receiving robust offers and avoiding future negotiations.

In this paper, the important risks, which were underestimated in the above four contracts and had traumatic consequences to the projects' progress when realized, are analyzed and discussed ex post. For each particular problem, proper mitigation measures are proposed, including existing contractual clauses rectification, administrative measures introduction and law amendments. The lessons learned and the subsequent proposals made are expected to contribute to the financial viability and stability of future concession contracts.

2. LITERATURE SURVEY

The need for renegotiation of concession contracts is not unusual; common causes are the underestimation of the project's cost, the overestimation of the project's future revenues and the significant unfavorable change of market conditions. According to World Bank data, 65% of the concession agreements for roads and other infrastructure projects involve renegotiation. It is noted that the incidence of renegotiation has been beyond the expected or reasonable levels and challenges the concession model's validity (Guasch 2004, Guasch et al. 2008). Furthermore, it is widely argued that the willingness of a government to renegotiate a contract, when known in advance, as well as the existence of mechanisms for the revision of the terms may create incentives for opportunistic bidding behavior (Ping Ho 2006, Guasch et al. 2008, Albalate and Bel 2009). In addition, the conditions of renegotiation are prone to political manipulation (Trujillo et al. 2002, Ng and Loosemore 2007).

Mexico's ambitious toll program consisted of 52 concessions, totaling over 5300 km of new highways in five years. When the first concessions opened to traffic the concessionaires experienced severe liquidity problems. According to Carpintero and Gomez-Ibanez (2011) this was due to a combination of causes, including: the underestimation of the construction cost by 30%, the overestimation by 40-50% of the traffic demand, the consequences of Mexican financial crisis on interest rates and currency value, the very short initial concession periods (12 years in average) and the unreasonably great length of new network. Furthermore, the companies were much more interested in construction than in operation while the publicly owned banks provided loans to the concessionaires after governmental pressure. The restructuring resulted in substantial lowering of the tariffs accompanied by extension of the concession period up to 30 years, extension of the payback period, reduction of the interest rate to a realistic level and increase of State's contribution.

Significant restructuring of concession contracts was also required in Spain as a result of the devastating impact of the recession on the risks undertaken by the private sector. According to Vassallo et al. (2012), traffic levels turned to be substantially lower that the forecasted, especially in cases where the motorways competed directly with a free highway. Furthermore, expropriations involved high cost overruns due to the court decisions that entitled the land owners to compensations even ten times greater. The government preferred to renegotiate rather than to terminate the contracts, as potential bankruptcy of the Concessionaire would be particularly costly for the State as well. In order to mitigate the effects of the large cost overruns and traffic revenues reduction, the government proceeded to the award of Subordinated Public Participation Loans (SPPLs) to the Concessionaires, extended the concession period and permitted the toll rise. At a later stage, the government guaranteed, through additional SPPLs, the 80% of the forecasted revenues for 2011-2013.

It is apparent that due to the stochastic nature of infrastructure investment preparation and implementation, particular attention must be paid towards the achievement of a fair risk allocation between the State and the Concessionaire. Ng and Loosemore (2007) note that this is not an easy task given the technical, legal, political and economic complexity of infrastructure projects and the range of constituencies involved. In the same line, Akintoye et al. (2001) argue that risk management practices are highly variable, intuitive and subjective.

Furthermore, based on previous research regarding 42 potential risks in concessions in various countries, Ke et al. (2010) made a combined comparison of the findings, which revealed that compared to China and Hong Kong, the private sector in the UK and Greece is expected to take full responsibility for a greater number of risks.

The literature suggests the implementation of certain rules towards the achievement of optimal risk allocation. Otherwise, according to Ng and Loosemore 2007, the public sector is merely gaining the illusion of risk transfer since it is likely that the risk will return in a more complicated form. Cooper et al. (2005) support that risks should be allocated to the party best able to manage them and at minimum cost. Loosemore et al. (2006) introduce specific criteria regarding, among others, the awareness, the capacity, the efficiency and the capability of the involved parties to undertake risks. In the same line, Abednego and Ogunlana (2006) are of the view that proper risk allocation requires the consideration of good project governance criteria including contract fairness, information transparency, continuous project control and monitoring, equality, effectiveness and accountability.

3. THE FOUR GREEK MOTORWAY CONCESSIONS IN TROUBLE

The four 30-year concessions foresee the construction of 644 km of new motorway in 5 years, the upgrading of 451 km of existing roads to motorway standards and the operation of 1,152 km (Table 1). In these concessions, numerous parties are involved (Table 2). Each

Concessionaire undertakes both the cost and risk of construction and operation and is responsible for the necessary financing over the State Financial Contribution (SFC). In case of Concessionaire's failure to meet his obligations, the contract foresees penalties etc. During operation period, the Concessionaire collects tolls from the project users in order to repay the loans to the lending banks and generate profit to his shareholders. The Concessionaire starts collecting tolls from the commencement date for the existing sections, even if they need upgrading. These concessions are subsidized by the State through the SFC; the EU contribution is estimated at about 65% of the SFC (Table 3).

Motorway concessions	**Length to Construct (km)**	**Length to Upgrade (km)**	**Length to operate* (km)**
IONIA ODOS	160	164	324
AEGEAN MOTORWAY	25	205	230
OLYMPIA ODOS	284	82	366
CENTRAL GREECE MOTORWAY	175	-	232

* including sections constructed by the State

Table 1: Motorway Concessions Length

Motorway concessions	Concessionaire Shareholders	Constructors	Foreign Banks	Greek Banks
IONIA ODOS	5	3	6	8
AEGEAN MOTORWAY	6	6	8	6
OLYMPIA ODOS	6	6	14	11
CENTRAL GREECE MOTORWAY	4	3	8	7

Table 2: Parties involved in the four Motorway Concessions

Funding Sources	**Amount**
State Financial Contribution (SFC)	1,950 m €
Toll Revenues	2,200 m €
Loan Capital	2,750 m €
Share capital (Shareholders Committed Investment - SCI)	700 m €
Total	**7,600 m €**

Table 3: Funding Sources

4. EX POST RISK ANALYSIS, LESSONS LEARNED AND CORRECTIVE PROPOSALS

4.1. Risk due to Scope

The Greek motorway concession programme has been very optimistic. Over a short period of time, the contracts foresaw the construction of a great length of motorway, even in sections where this was not necessary due to low traffic. This increased considerably the projects' budgets and, subsequently, the borrowing needs. Moreover, a cross subsidy policy was adopted in the context of the country's regional cohesion: the user pays also on existing motorway sections near the major cities and the respective revenues repay the construction of new sections at the periphery of the motorway network. Unfortunately, the split of road sections per contract was not successful and led to uneven contracts regarding their borrowing needs, e.g. low borrowing for Ionia Odos accompanied by large future revenue for the State, high borrowing for the Central Greece Motorway and operation subsidy from the State. Consequently, the less the financial stability of a project, the bigger the difficulties it faces in recession times. Furthermore, the Council of State has cancelled the Environmental Terms for a 25 km section of Olympia Odos; therefore this section cannot be constructed. Also, huge delays have occurred in the completion of the sections that the State has to construct and deliver to the Concessionaires.

In order to mitigate ex-post the above problems, the scope of Olympia Odos and Central Greece Motorway has to be reduced by 40% approximately. This will lead to a significant reduction of the construction cost (and of the loan amounts respectively), a fact which will facilitate the long term viability of those projects; it will also allow the timely construction completion, i.e. at no European subsidy loss. The State should have opted for a step by step development of the motorway network, exploiting further during the extended construction period the revenues from existing sections in order to reduce the magnitude of loans; furthermore, it should have not opted for motorways in low traffic sections.

4.2. Risk due to Stakeholders

The high budgets of the tendered concessions (€ 1 bn to € 3 bn) led to Concessionaires with 4-6 shareholders (companies), to Joint Ventures with 3-6 construction companies and to Lending Consortia with 14-21 banks. It is obvious that the high number of participants complicates the decision making process. In the particular case of decisions that need to be taken by the Lending Consortia with unanimous consent (e.g. deadline extension), it is probable that Banks with low participation (and thus exposure) will block them. Furthermore, the fact that all concession shareholders and constructors participate in more than one projects and all Banks finance more than one projects, creates a phenomenon of communicating vessels in any negotiation and problem solution. Also, the State had no proper consultation with Regions, Municipalities and local interest groups before tendering the projects. This has led to appeals to the Council of State against toll pricing and environmental permits, as well as to friction with parliamentarians, local politicians, citizens and users.

The State should have tendered more concessions but smaller, e.g. each with a budget of no more than € 0.5 bn; this would have enabled the formation of smaller groups of shareholders, constructors and lending banks and would have streamlined the decision making process. Moreover, the State should have planned extensive consultation with all interested parties well in advance in order to limit opposition to the projects and avoid negative decisions by the courts and the subsequent technical modifications, delays and costs.

4.3. Risk due to Design

The Basic Design (i.e. pre-design stage) under which the projects were procured should be improved in many cases in order to take into account the specificities of certain areas, environmental problems encountered and reasonable requests of the local population. The functionality improvement should be achieved with minimal impact on approved time schedule and without financial burden to the State (value engineering etc). For example, in Ionia Odos more than 20 technical modifications were identified; they include minor improvements, such as the addition of underpasses, as well as important re-alignments leading to major changes, such as the addition of a 3 km tunnel in Klokova (instead of a series of bridges and embankments) and the construction of a series of embankments at Avgo (instead of an 1 km bridge).

To practically re-engineer the projects, a coordinated action from all parties involved is needed, i.e. State Service, Concessionaire, Constructor, Independent Engineer and Banks' Technical Advisor. A working party should promptly estimate in every project the cost of the technical modifications against the Basic Design; the State and the Concessionaire will resort to the foreseen contractual dispute procedures in case of disagreement. The State should have tendered the projects with the procedure of Competitive Dialogue, foreseen in the respective European Directive; the Dialogue enables the thorough examination of the technical and other issues by all competitors before the finalization of tendering documents.

4.4. Risk due to Legal Consents

The projects faced important delays in the issuance of the required legal consents. The contracts provided for State obligations which were almost impossible to be met, e.g. delivery of project site within 12 months or environmental licensing for quarries within 4 months. Delays were also due to the refusal of Public Utilities Organizations to relocate their networks, where needed, at their own expenses as specified in the contracts; this led to time consuming legal fights in courts. The Concessionaires and the Constructors raised significant claims for compensation due to the delays; these exceed in total the amount of € 1 bn (for all projects), but their proper evaluation through the contractual arbitration procedure is expected to substantially reduce this amount.

The State should have not included in the contracts such unrealistic provisions for delivering the site to the Concessionaires in short time. Regarding expropriations, the State should have applied as early as possible the Olympic Games Special Law (article 7A of the Mandatory Property Expropriation Code) for the acceleration of expropriations. Regarding archaeological investigations, a very sensitive issue in Greece, the State should have promoted a Memorandum of Understanding between the Ministries of Culture and Infrastructure to streamline and monitor the processes. Furthermore, the State should introduce by law the creation of a single Special Archaeological Service per big project (i.e. to take the responsibility from local Services) and the outsourcing to contractors specialized in archaeological investigations. Regarding environmental licensing for quarries etc, the State should simplify the extremely complicated procedure, which is now the most important impediment to the progress of all public works. To cut the Gordian knot of legal consents and reduce risks and claims, the State should adopt the tendering of small preliminary works contracts prior to the main ones. These contracts will be awarded immediately after the road alignment is specified and the Joint Ministerial Decision on Environmental Terms is published. Their scope will include land occupation, public utilities networks relocation, archaeological investigations advancement and culverts construction (aiming to enable the movement of heavy machinery along the axis). They will be terminated as soon as the main contract is awarded.

4.5. Risk due to traffic

During the period 2002-2003, the State conducted traffic counts and surveys (origin / destination, value of time etc) for all motorways and allowed Concessionaires to access primary data. After adapting these and conducting their own traffic counts, the Concessionaires elaborated traffic forecasts (in an optimistic manner) and used them to calculate revenues in their bids. The State never examined the Concessionaires surveys and traffic models since contractually the traffic risk lies fully with them. Traffic forecasts depend on various parameters; GDP is the one affecting traffic in a more immediate and linear way. The financial crisis in Greece led soon to a substantial decrease in traffic; at the same time, various institutions processed new conservative forecasts showing a sharp GDP decline. Taking these into account, the Lending Banks requested the update of the traffic volume forecasts, which showed a decrease of 40% as compared to those at the commencement of the concessions. As a result, the Banks questioned the long-term viability of the projects.

It should be noted that forecasts on similar cases can be made with an adequate degree of certainty for a five year period only; after that, a linear extrapolation combined with a downward trend is applied. Therefore, pessimist forecasts made in such an adverse financial environment should not be considered as a basis to extract results and be committed for the following thirty years. In any case, the State should have not allocated the full traffic risk to the Concessionaires, even if they had accepted that; it is not possible for any concessionaire to bare this risk in case of traffic collapse. Before concluding the loan agreements and as part of their approval process, the Lending Banks and the Concessionaire in each project structured and agreed among themselves a financial model (Lenders Low Case - LLC / stress scenario), which takes into account a traffic decline of 15% - 20%; in case of further traffic decline the repayment of the loans and (more so) the Concessionaires' shareholders investment cannot be secured. The correct practice should have been for the State to define in each contract a traffic threshold and a respective rescue procedure. Moreover, the traffic surveys should have been submitted to the State and provide not only the traffic volume, but also the detailed toll revenues calculation, based on vehicle-kilometers, and the toll fees per vehicle category, given that the tender provided for a maximum toll rate per kilometer travelled per type of vehicle.

4.6. Risk due to tolling

A number of arrangements and options of the toll policy determined in the contractual documents have proven to be problematic in practice, especially within the current adverse economic situation. The State allowed the Concessionaires to operate open toll systems, which led to high (non-proportionate) charges for the users living in the vicinity of frontal toll stations where there is no alternative lateral road network. Furthermore, in order to decrease borrowing, the State imposed tolls in sections under upgrading, i.e. with low level of service due to on-going construction. As a result, a citizens' movement emerged and noumerous users refused to pay tolls; this had a negative impact on revenue, on top of the traffic decrease, and increased its risk.

The State should have allowed, as part of the toll policy, for a substantial reduction (e.g. 50%) in sections under construction, discounts for frequent users and subsidization for some user categories from social policy funds (e.g. for disabled persons). In parallel, the State should have provided for more austere administrative sanctions for toll violators. The State's mid-term target should be the implementation of an electronic free-flow toll collection system with proportional vehicle charging in all motorways (one card/OBU – one bill for each vehicle), in accordance with the EU interoperability provisions for the Trans-European Road Network. Appropriate legislation would mainly address the violators issue and the settlement of payments between Concessionaires through the establishment of an Information and Payments Exchange Center within the Ministry of Finance.

4.7. Risk due to Financing

The collapse of toll revenues, in conjunction with the Concessionaires' contractual obligation for paying to the State its revenue share in priority, resulted in a short term funding shortfall during construction and in a long term inability to service debt and return shareholders' investment. It is noted that the contracts provide for no State guarantee for loans repayment; in a way to counterbalance that, the contracts foresee the frequent revision of the financial models, giving thus the Banks the opportunity to question the viability of the projects; this is crucial during the construction period. Also, the contracts and financial models foresee during construction period that the drawdown of the long term loans is possible after that of the share capital and SFC (in the financial models, a series of short term bank loans substituted the SFC installments). Given that the crisis occurred at the early stage of construction, this rear end loan financing reduced substantially the long term engagement of the Banks and increased their negotiating power. Moreover, the Concessionaires hedged the loans; since there was a long delay to site delivery by the State and the loans could not be used, the cost of breaking and rearranging the swaps became considerable. On the basis of the above and of the prevailing economic and financial situation (increase of financing cost, reduction of liquidity, country risk), the Lending Banks requested the renegotiation of the loan agreements, opting to more than triple the contractual lending interest rate margin (1% on top of Euribor) and to reduce their exposure.

The State should assure from its share of projects' revenue the Concessionaires' and Banks' cash flow according to the traffic corresponding to the LLC, subject to the condition that any future increase in traffic revenue would be used to compensate the State for its contribution (loan to the project). In order to reduce the funding shortfall, the State should extend the construction period (during which the toll revenues finance the projects' construction), adjust appropriately the projects' time schedules and reduce their scope. In parallel, the State should insist on the rationalization of the operational expenses without reduction of service and safety levels. Moreover, the State should consider measures to improve Banks security, e.g. reduction of loan capital and tenor and increase of debt service cover ratio. The State should also investigate additional financing sources (e.g. EIB loan, bonds development) for the completion of the projects.

CONCLUSIONS

The above ex post analysis proves clearly that the Greek State failed to properly investigate all important risks ex ante, i.e. before tendering the concessions. The financial crisis and subsequent traffic decline had an almost disastrous impact on the viability of the projects; the State had to learn its lessons the hard way. In the face of the current conditions, projects viability will potentially be achieved after renegotiation at a lower level compared to the contractual provisions, with proportional losses for all parties involved (State, Concessionaires and Lenders). The proposed measures include rectification of existing contractual clauses, streamlining of administrative procedures and new legislation. They can contribute twofold: first, to the progress of negotiations, independently or in combination, and second, to the effectiveness of future contracts. In conclusion, the most important lesson for a prudent decision maker of the State is the need to be pro-active and require an extensive and in depth ex ante risk analysis of future concessions; any country's economy will fluctuate more or less strongly during the long concession period. Therefore, provisions should be included in the tendering documents to enable fast renegotiation and adoption of compromise solutions. Otherwise, a potential political risk may emerge, when the Parliament, in its new representative composition, will have to ratify the contractual amendments.

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APPROACHES FOR DEVELOPING A RISK-BASED INTELLIGENT AGENT SYSTEM FOR INTERNATIONAL CONSTRUCTION

Jaebum Lee
Master Student, Yonsei University, Seoul, Korea, mamafan@yonsei.ac.kr

Kang-Wook Lee
Ph.D. Candidate, Yonsei University, Seoul, Korea, celebrity3@yonsei.ac.kr

Jung Ki, Lee
Master Student, Yonsei University, Seoul, Korea, tommyjtl@yonsei.ac.kr

Seung Heon Han
Professor, Yonsei University, Seoul, Korea, shh6018@yonsei.ac.kr

Du Y. Kim
Full-time Lecturer, Kyungil University, Gyeongbuk, Korea, duyonkim@kiu.ac.kr

Wooyong, Jung
Team Leader, ERM TF Team. SK Engineering & Construction, Seoul, Korea, trustjung@gmail.com

Abstract

The international construction industry over the last decades has shown that construction firms are facing a highly uncertain business environment. Although risk management has been regarded as one of the keys to success in surviving market and project volatility, researches on risk management have been limited in that; (1) existing approaches are not well associated with the corporate-level decision making process, (2) researches hardly utilize systematic/objective and evidence-based data sets in risk analysis, and (3) they often fail to consider knowledge sharing among various stakeholders. To overcome these limitations, this paper proposes a novel approach to develop an advanced risk management system by adopting the "intelligent agent" concept. Accordingly, we first conducted a comprehensive literature review to identify ideal but practical system requirements. Subsequently, a holistic system framework and a relational database structure are established by linking with the system requirements. The proposed system includes a total of seven risk management modules in association with the key decision making process on the corporate level. These modules are equipped with each of quantitative assessment algorithm, including a knowledge sharing program, a host country evaluation, a portfolio-based country selection, bad-project screening, a project contingency evaluation, and risk strategy development. It is expected to provide not only user-friendly platform incorporated with automated reasoning and feedback mechanism but also evidence-based information via more extensive/objective database.

Keywords: International construction, Corporate decision-making process, Risk management, Intelligent agent system, Relational database

1. INTRODUCTION

International construction market is usually exposed to inherently complex and highly uncertain conditions, which cause a higher possibility of project failure (Han et al, 2007). To overcome this problem, many studies on risk management system have been conducted (Choudhry et al, 2013, Tang et al, 2007, Vinit et al, 2007). However, previous researches primarily focused on (1) individual project-based risk management, (2) analysis with fragmented and/or subjectively biased data sets, and (3) an insufficient amount of knowledge sharing among the various project participants. These approaches cannot support decision-making compatible in a corporate level, because they are lacking connectivity with an entire overseas construction workflow. In addition, analysis by a subjectively biased data set is often producing limited and unreliable results to the user. Insufficient knowledge sharing between project participants is also likely to create ineffective collaboration environment and thus, increase the user's loads of work. Therefore, this paper presents an alternative and advanced risk management system that includes an intelligent concept to reduce the aforementioned limits. A practical and efficient intelligent system should provide; (1) automated reasoning, (2) a feedback system in a user-friendly interface, and (3) evidence-based information to be used and updated in the system. In the current research, practical modules covering the entire life cycle of an international construction project to support the user's decision making are derived through an extensive literature review. The requirements for each module are then structured as data elements. This paper develops the data structure and the system framework for managing these data elements by applying data design theory. Finally, we tested the prototype of the proposed system through an example module.

2. OVERVIEW OF PREVIOUS APPROACHES

Research on risk management systems in global construction has been widely conducted due to the inherent volatility of the overseas construction projects. Specifically, studies on deriving a framework for a risk management system were performed by Shou et al. (2004) and Zizhi et al. (2012). Further research was also performed to develop a system based on these frameworks with various methodologies to meet the purpose of each system's aim in terms of the objective of risk management requirement. Representatives include case-based reasoning for the experience-intensive problem (Vinit et al., 2007), artificial neural networks for the total risk value (Pedro, 2005), and the fuzzy failure mode and effect analysis (FMEA) & fuzzy analytical hierarchy process (AHP) for mapping the relationship between risk impact and the probability of occurrence (Mohamed et al., 2010). The common attributes in these studies are primarily centered on the perspectives of individual projects and contractors, where the focus is on risk monitoring and quantitative evaluation of a given project. The data employed in these studies are also considered fragmented and subjectively biased. Regarding this issue, Han et al. (2008) proposed a risk management system through fully integrated risk management system (FIRMS), integrating the corporate and project levels but not the country level. In addition, Rafiq et al. (2013) stated that, in risk management, information sharing among different participants in various projects is essential. However, the aforementioned systems do not properly allow sharing of the project participants' knowledge and feedback between system and users. In summary, the methodological aspects of risk management system are well defined; however, the philosophical aspect of which risks are managed and learned is still vague. Dikmen et al. (2008) proposed a tool for the construction of a lesson-learned database from the risks in the whole project life cycle. It can define, assess, monitor, store, and retrieve risk information from previous experiences and lessons, but the proposed tool in the present research stays at project level.

Consequently, this paper attempts to develop an intelligent risk management system that integrates country, corporate, and project levels over the whole life cycle workflow of international construction. In addition, a circulation structure is developed based on a web-based system allowing system-user and user-user feedback to accumulate and share risk information and knowledge learned by previous cases and lessons from the project participants. Accordingly, we propose a web-based intelligent system framework that supports decision making in the whole project life cycle workflow of an international construction integrating the country, corporate, and project levels. Through an extensive literature review and expert interviews, the components of the risk management system and conceptual framework are discussed in section 3, and the prototype of web based system development example is given in section 4.

3. RISK-BASED INTELLIGENT AGENT SYSTEM

3.1. Framework of the risk management process

The intelligent risk management system (IRMS) supports decision making on the overseas construction project process through a systemized risk evaluation under complex and risky business environment at the country and projects level. In its entirety, IRMS covers risks of the whole project life cycle. The main work process flow of overseas construction project is divided into the country exploration phase, the pre-screening phase, and the bidding & construction phase. In the country exploration phase, decision makers of a firm choose an attractive global market at the country level. In the pre-screening phase, the user makes a go/no-go decision at the corporate level by considering the firm's capacity and wide spectrum of project conditions. In the bidding & construction phase, the user makes a specific decision about participating on a given project based on the project information. After capturing the project, users continuously manages risks during the project execution. Most previous research focused on the risk management of the bidding & construction phase at the project level (Han et al, 2008). With considering the importance of risk management in the pre-project planning phase, this research partitioned the project upstream phase into the country exploration phase and the pre-screening phase for systematic risk management. To address all these requirements, this paper developed the intelligent risk management system framework shown in figure 1, which is arranged in accordance with the key work process.

IRMS accumulates data that are spontaneously generated during the decision making process and induces users to become a network. Internal IRMS is consisted of a system database, a data mart and a risk management module. Externally, there is a system manager who manages the system and users who can communicate fluently between the internal and external systems through feedback. According to the data mart and the user input information extracted from the system database, each risk management module of the internal intelligent system supports the firm's decision making in conjunction with the major workflow process of the overseas construction project. The information collecting phase (country exploration phase) covers the host country evaluation, the portfolio-based market entry decision and the real option based market entry decision modules. The bad project screening module is included in the pre-screening phase. The project contingency evaluation and the risk strategy development modules belong to the bidding & construction phase. Finally, the knowledge sharing program module provides useful information that can be used for the user at any point of the risk management process.

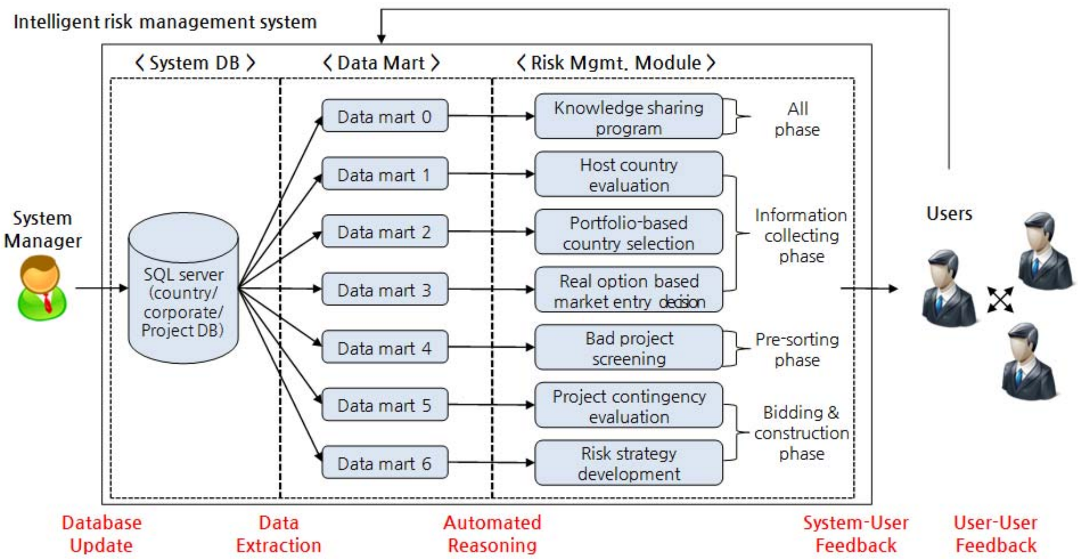

Figure 1: Intelligent risk management system framework

3.2. System Database & data mart

The system database for the intelligent risk management in this paper employs market, corporate and project level data. The market and corporate level databases are where the pre-qualified/objective secondary data and the database of the questionnaire analyses in the previous researches are objectified. Because credibility is important for the objective secondary data (Lee, 2008), this paper adopts the objective secondary data including Global Insight, the World Bank, and Engineering News records. For the effective system management and update, the crude data from the entire database produced by the aforementioned organizations – the construction outlook database from Global Insight, the Worldwide Governance Indicator & Doing Business database from the World Bank, and the top 225 international contractors - are adequately used. The Korean firms' real performance database from the International Contracts Association of Korea (ICAK) as a secondary data and questionnaire database for detailed risk information are also accumulated to analyze the wide and objective data at the project level database. The coverage level of each data source is shown in table 1.

Coverage level	Data Source	Contents	Remarks
Country	Global insight (GI)	Market Information	69 countries (2009)
	World Bank (WB)	Political Governance level	215 countries (2012-2013)
		Business environment level	185 countries (2012-2013)
Corporate	Engineering-	Revenue Information	225 firms (2012)
	News Record (ENR)	Entry nation Information	225 firms (2012)
Project	ICAK database	Detailed project Information	7,044 projects(1990-2012)
		Bidding Information	12,504 projects (1990-2012)
	Expert questionnaire	Project Risk factor	138 projects (1990-2010)

Table 1: Database coverage

The respective module data marts are automatically extracted from the system database according to the required input data from each module. The extracted data mart updates automatically based on the user input data through the feedback system, which accumulates information by itself during the system launching process. Through the module data structure linked with the data mart, IRMS performs risk management with using the pre-accumulated data and the input information that reflects the firm's business situation. Therefore, IRMS can support the user's various decision-making processes based on the analysis results of the respective modules in accordance with firm's business goal at the level of market, corporate, and project.

3.3. Risk management modules

This research developed the risk management modules followed by risk management requirements for each work process to increase the applicability in reality and to perform risk management across a whole life cycle of an overseas construction project. Seven risk management modules are developed by reviewing the relevant literature on this subject. Through a workshop consisting of 8 experts with over 15 years experience in a relevant field, the relationship between the risk management module and the overseas construction workflow was evaluated and validated. To discuss the practical requirements for risk management system, more detailed information about each module was presented as follows.

Knowledge sharing program (Module 0)

The knowledge sharing program module provides advanced information about the current issues and key trends in the overseas construction market and the channel protocol for sharing companies' learned lessons by the previous cases. This module provides information about target markets and supports decision making through a firm's whole business cycle with shared analysis result information through web search or gathering from users' feedback.

Host country evaluation (Module 1)

This module builds upon our previous research (Lee et al., 2011), developed for the host country evaluation. The host country evaluation module supports decision making about target market selection according to the attractiveness evaluation of a given market and the firm's preference or priority for market entry reflecting the risk attitude of a specific firm during the information collecting phase. This module provides a target market attractiveness score that is calculated by gauging 3 dimensions – (1) market opportunity, (2) business environment, and (3) expected performance – based on data such as the market growth rate, the market size, the market risk level and the market volatility. This module is devised to calculate the market attractiveness scores based on individual weights determined by the user's risk attitude with the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

Portfolio-based country selection (Module 2)

This module also builds upon our previous research (Jung et al., 2012). The portfolio-based country selection module helps to create a strategy for the firm's market entry portfolio and proposes new target markets. This module employs a multi-objective genetic algorithm (MOGA) based on Markowitz theory to find the optimal solution for more diversified investment that can maximize the market growth rate and profitability as well as minimize the revenue volatility. With this module, the user can presume the appropriateness of positioning in the firms' current and future revenue portfolio. Further, the module also recommends a new target market revenue portfolio.

Real option based market entry decision (Module 3)

This module is extended based on our previous research (Kim et al., 2012). The real option based market entry decision module is designed to support decision making about the entry timing of the firm's target market. Two types of data about the firm and the target market – the firm's (1) capital structure, (2) initial & annual cost, and (3) cost volatility and the market's (1) market growth rate volatility, (2) GDP, and (3) inflation rate - are used for the analysis. With these data, the module performs quantitative and probabilistic analysis using a Monte Carlo simulation (MCS) and Real Option Analysis (ROA) about the firm's expected NPV according to the net cash flow in the target market. The module result provides information about the expected NPV with the market entry timing, the profit occurrence probability, and the optimal entry timing.

Bad project screening (Module 4)

This module is also extended based on our previous research (Jung, 2010). The bad project screening module provides a guideline for screening bad projects in the pre-sorting phase. In the model constructing process, data with 6 risk categories – (1) country risk, (2) economic risk, (3) project condition, (4) project characteristic, (5) organization capability, and (6) financial capability - are composed of 32 factors, and the Korean firm's real performance data for the overseas project are used. This module provides a guideline with a scaled score of 32 factors based on the firm's strategy. The scaled score is calculated by 3 data mining techniques, (1) an artificial neural network (ANN), (2) a linear discriminant analysis, and (3) a decision tree algorithm. The guideline allows the user to compare the pros and cons of these data mining techniques. Using practical guidelines, the module assists the firm in making a preliminary decision about screening out bad projects from the candidate overseas projects.

Project contingency evaluation (Module 5)

Jung (2010) also indicated that the project contingency evaluation module supports the allocation of project contingency based on the firm's risk attitude during the bidding & construction phase. Targeting 137 real cases of overseas construction projects, this research utilized in-depth risk information about 71 cost volatility risk factors, which were scored by experts' risk evaluation of similar projects and the project cost volatility information. Using this information, this module performs a risk evaluating simulation on a similar project. During the simulation, the module employs a nonparametric probability distribution by considering the covariance effect between risk factors. The simulation result provides the cost overrun interval and the cost overrun probability distribution of the target project based on the cost volatility information of a similar project. The user is advised to make a decision about allocating contingencies by the degree of cost overrun and the probability distribution of possible cost overrun.

Risk strategy development (Module 6)

The risk strategy development module provides countermeasures priorities to possible risk factors during the project implementation as well as information collection about the primary risk response/control strategies. This module reduces the workload for the user through providing information on 71 detailed risk factors (in module 5) before construction begins. The module then predicts occurrence frequency, and the probability of each risk factor, which is developed using detailed risk factor information with a conditional probability by utilizing Bayes' theorem. After construction begins, the user can obtain the real occurrence frequency of the primary risk factors through updating relevant information by feedback system. Users can also monitor the effectiveness of each risk management strategy by the same way.

4. ILLUSTRATIVE EXAMPLE

Due to space limitations, this research presents a simple example of an intelligent system's data structure and algorithm, designed for a real option based market entry decision module (module 3). The real option based market entry decision module, which integrates the country and project levels, performs real option analysis on profitability with market entry timing based on the firm's risk attitude and performance.

To apply real option analysis, the firm's cash flow volatility depending on the market entry timing is represented by a binomial lattice. To increase the reliability of the cash flow prediction, this paper performed a Monte Carlo simulation with 1,000 iterations with risk neutral up and down probabilities depending on the risk free rate. The data mart required in this module extracts information from the system database which includes ENR, GI, and ICAK data combined with user input, and then generates the result for decision making about market entry timing. The user input is represented as two inputs; one is information for the identification of the user, and another is for the analyzed result derivation. In addition, partial user input factors will be loaded automatically later by data accumulation of the feedback system during the user input process. The module output as a result of analysis is 'Expected NPV by market entry timing', 'Minimum revenue boundary for market entry', 'Optimal market entry timing by risk neutral NPV' and 'Firm's financial risk profile'. The data structure in this module is built with object-oriented modeling. An objective-oriented modeling allows the creation of a complex program database in a simple design with the object's attribute and method oriented structure. In addition, the data structure created for each module can easily be combined and partially updated. This research implemented an actual system based on the derived data structure. The data structure design for data coding is visualized through a Unified Modeling Language (UML) Class Diagram, as shown in figure 2.

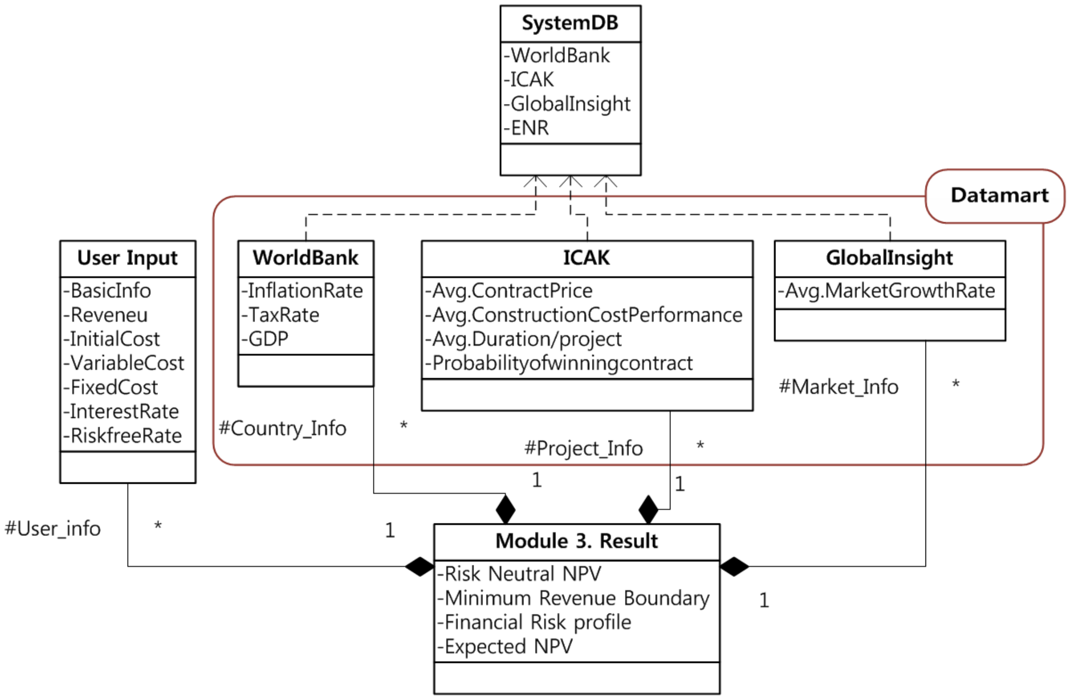

Figure 2: Class Diagram of Module 3

Each class is composed of a system database, a data mart, user input, and the module result. The system database is a data pool, from which the data mart extracts the information for system analysis. The data mart includes the classes of World Bank, ICAK, and Global Insight that have information on the target country at the country and project levels from the system database. All information formulated from the data mart class and the user input about the firm's basic information and capability produces the module result for the user. This system is created in a web-based system for easy access to the users at the firm's construction sites and, overseas branch offices, and the results reflect the variety of users' feedback. The picture shown in figure 3 is the part of web-based system of module 3, which shows the result of the analysis.

The data used in module 3 are from the Korean firm Hyundai E&C for a Qatar market entry scenario. The image shows the result from module 3 of the optimal market entry timing through the simulation. The market entry timing result shows the expected NPV and NPV ratio in each year for the next 5 years.

5. CONCLUSION

This research developed an intelligent risk management system to support decision making by evaluating various risk factors affiliated with an international construction workflow for coping with uncertainty. In contrast to previous researches, the proposed system supports the decision making at both the corporate and project levels through the module applications over the whole life cycle of the international construction project. An automated reasoning analysis was deployed through a systematic risk assessment and simulated optimization. In addition, the feedback system between the system and the user allowed real-time updating and extensive analysis. The user's knowledge sharing through both qualitative and quantitative analysis of the risk factors was also used to support the decision making with a concept of intelligent agent. Through the illustrative example, this research is expected to contribute to the academic and industry field by facilitating improved decision making support. Since this system requires a certain amount of users experience and a data collection period to develop the database, future research will more concentrate on developing and validating the efficiency of the system by monitoring database-updating process through the autonomous and self-ruling software agents that goes beyond current system by working continuously in the background.

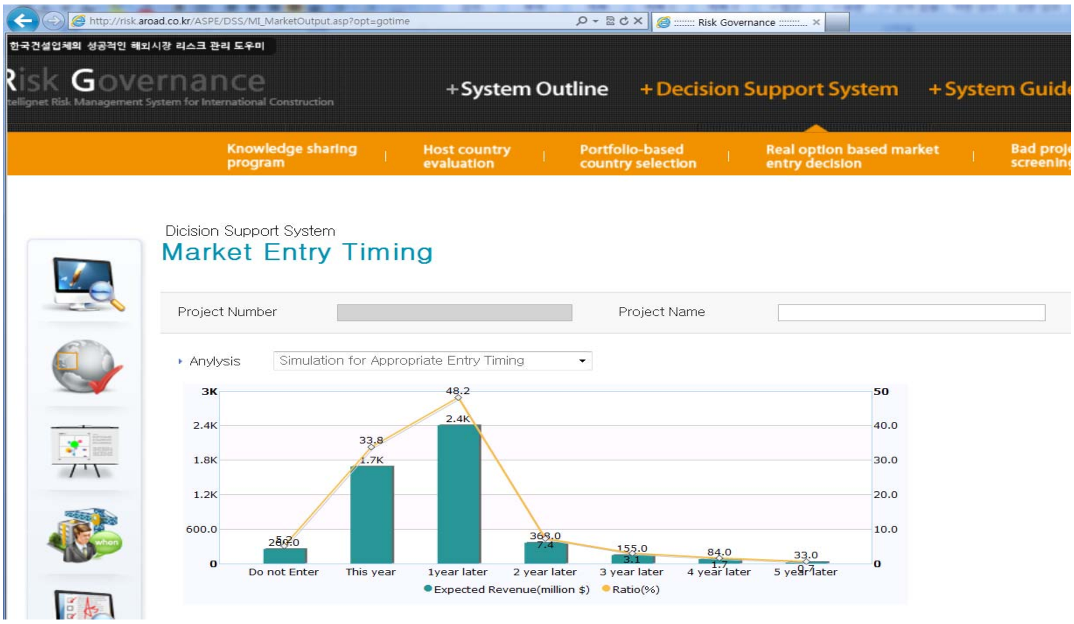

Figure 3: Result of Module 3

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ENERGY AND TEMPERATURE ANALYSIS FOR CONCRETE BUILDINGS

Kuo-Liang Lin
I-Shou University, Kaohsiung, Taiwan, kllin@isu.edu.tw

Sho-Hong Ju
I-Shou University, Kaohsiung, Taiwan, 10mpeter@gmail.com

Abstract

Air conditioning is a standard feature of buildings in many tropical and subtropical countries like Taiwan. In summer, cooling accounts for the primary source of housing energy consumption. With energy price rising and increasing concerns over global warming, it is essential to reduce the use of air conditioning systems. Most buildings in Taiwan are made of concrete. Insulation, airtightness, orientation, location, and building type are the possible parameters affecting the energy consumption and room temperature of concrete buildings. To understand the impacting magnitude of these parameters, our research team conducted a series of simulation to estimate energy consumption and room temperature of concrete buildings, utilizing Autodesk's® sustainable design software Ecotect Analysis®. Two typical types of concrete buildings (5-story single family house, and 12-story high-rise condominium) in Taiwan are modeled and used as the test beds of the simulation. Research results show that good building insulation, enhanced airtightness, and careful selection of building location and orientation can effectively reduce AC consumption more than 50%.

Keywords: building insulation, Ecotect Analysis®, energy consumption, simulation

1. INTRODUCTION

Most buildings in Taiwan are made of concrete, and concrete is a poor insulator, while solar radiation heat can easily penetrate concrete frame and enter the room. During summer time subtropical areas like Taiwan, the sun's powerful rays radiate down and inside buildings, concrete walls heat up and indoor temperature raises. Most people has no choice but to turn on the air conditioning and watch the electric bill soar

After sunset, outdoor temperature falls and it becomes more comfortable, but inside concrete buildings, people still suffers from high temperature if air conditioning is not turned on. Concrete's high heat absorbing capacity make it store a great amount of solar heat from daylight. The envelope gradually releases heat and prevent the indoor rooms from tremendous temperature reduction. In a typical summer night, temperature inside concrete building can easily maintain mid-30 degree celsius without AC.

Adding thermal insulation and improving air leakage are the two major ways to increase comfort of concrete building. Thermal insulation is to reduce the amount of heat that escapes or enters by creating a barrier around building enclosure. Air Leakage is the unintended airflow between indoor and outdoor through a building enclosure. Air leakage can greatly reduce insulation R-value so It is important that buildings achieve a high level of airtightness in order to maintain energy efficiency and provide comfort for occupants.

To understand the impacting magnitude of Insulation, air leakage, orientation, and location, our research team conducted a series of simulation to analyze energy consumption and room temperature changes of concrete buildings. Utilizing Autodesk's® sustainable design software Ecotect Analysis®, two typical types of concrete buildings (a 5-story single family house, and a 12-story high-rise condominium) in Taiwan are modeled and used as the test beds of the simulation. The goal is to find the best building characters that achieve the ultimate comfort.

Autodesk Ecotect Analysis® is a 3-D building simulation package capable of a series of tasks, including thermal analysis, lighting analysis, daylight analysis, shadows analysis, and acoustic analysis. Ecotect® can be considered a conceptual sustainable design tool that can assist architects in assessing building's performance in preliminary stages. Academic studies related to Ecotect® include the following:

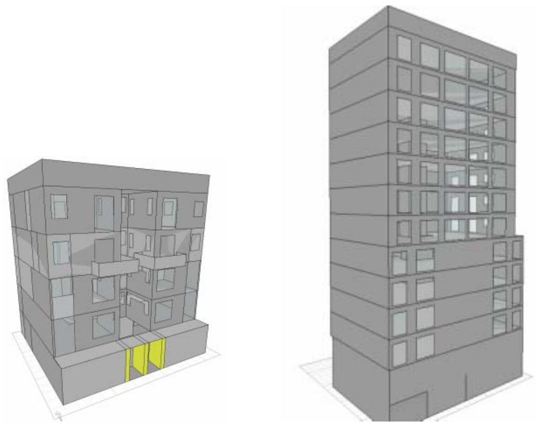
Tarabieh compared three simulation tools (Autodesk® Ecotect Analysis, EnergyPlus, and NEN2916) with the same input data and weather conditions on a typical building and concluded that the data integrity, expert level, and assumptions play a pivotal role in obtaining successful results (Tarabieh 2007). The simulation results from each of the tools were compared with the metered data, and Ecotect® presented a relatively fair result. Lien's study (Lien 2011) used Ecotect® in estimating government agency energy consumption in Taiwan. Window open ratio, building floor space, personnel density and climate regions are the main factors considered in the study. Motz (2012) ran two case studies, an office and a residential building, using Ecotect®, and concluded that, by modifying a building's components, it is possible to reduce space heating and cooling energy requirement for a house and office building by up to 96% and 87% respectively.

Prior to applications of Ecotect®, many other computer-based modeling and simulation tools are also used for predicting energy and environmental performance of buildings and their systems (Yin et. Al. 2010, Issa et. Al. 2009). In 1986, a non-profit society of building performance simulation researchers, developers and practitioners (the International Building Performance Simulation Association, IBPSA) has established to improve the built environment (Hensen et al., 2002). Modeling and simulation can play an important role in building and systems design, operation, renovation or management of decision making process (Hensen et al, 2001).

2. RESEARCH DESIGN

Situated in Eastern Asia at the boundary between the Philippine Sea Plate and Eurasian Plate, Taiwan is an earthquake-prone country. To prevent damages from major earthquakes, Taiwan has strict building codes that make reinforced concrete the primary material for residential buildings. Two types of residences are often seen in Taiwan: 5-story single family house, and 12-story high-rise condominium. Most single family houses do not stand alone due to towering land cost. A popular style of low-rise residence is a twin unit consisting of two identical houses. The other popular type is high-rise condominiums. High-rise residential condominiums in Taiwan are usually under 50 meters, and about the height of 12 to 14 stories. Taller buildings require additional structural and urban impact assessments which lower developer's interest in pursuing extra height.

Figure 1 shows the two typical building types modeled for this study. Basic assumptions of these buildings are described as follows:



Twin 5-story single family house 12-story condominium

Figure 1: Models studied in the research

(1) In occupancy and operation setting, the occupancy of the 4-story single family house is set at 6 residents including grandparents, parents, and a pair of kids. Grandparents stay at home all day, and the other four leave at 8:00am and come back at 6:00pm. In the 12-story high-rise condominium, each story has two living units, and the occupancy of each unit is 4, including the parents, and a pair of kids. All four leave at 8:00am and come back at 6:00pm. In both cases, human activity level at home is in sedentary model at 70W.

(2) Internal gains (values for both lighting and small power loads per unit floor are), sensitive gain is set at 5 W/m², and latent gain is 5 W/m², in both cases.

(3) In internal design conditions setting, clothing is set at 1.0, relative humidity at 60%, air velocity at 0.5m/s, and lighting level at 300 lux.

(4) Air condition is turned on when room temperature is above 26℃ in a 24-hour setting.

(5) Windows remain close all time.

Taiwan has 3 major cities: Taipei, Taichung, and Koahsiung, and their weather information from 1981 through 2010 is provided as in Table 2. Kaohsiung is considered the hottest among three.

Table 2: Weatherinformation from 1981 to 2010 --Mean Temperature (Unit:°C)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Taipei	16.1	16.5	18.5	21.9	25.2	27.7	29.6	29.2	27.4	24.5	21.5	17.9	23.0
Taichung	16.6	17.3	19.6	23.1	26.0	27.6	28.6	28.3	27.4	25.2	21.9	18.1	23.3
Kaohsiung	19.3	20.3	22.6	25.4	27.5	28.5	29.2	28.7	28.1	26.7	24.0	20.6	25.1

Weather Data – Major Cities 1981~2010 (data from Central Weather Bureau 2013)

Building orientation in this study refer to solar orientation which is the sitting of building with respect to solar access, and the orientation defined as the most important facade of the building, which receives the most solar energy. Two orientation options are modeled in the study: "facing west" representing the case with greatest solar heat reception during summer time; and "facing north" representing the case with greatest wind chill reception in winters.

Building insulation level has two options: "Traditional Insulation" and "Extended Insulation". "Traditional Insulation" is the most common RC building envelope in Taiwan, using ceramic tile as wall finishing material, and preliminary roof insulation with lightweight concrete and thin Polystyrene Foam, while windows are mounted with traditional glass. With ceramic tile covering, preliminary roof insulation and traditional glass, the envelope exibits a fair thermal conductivity (U-value) of 3.230 W/ m^2·k, 1.00 W/ m^2·k, and 6.00 W/ m^2·k, on the wall, roof, and window respectively. Table 3 shows the material composition of "Traditional Insulation".

"Extended Insulation" adds expanded polystyrene (EPS) to the wall and roof plus double-layered Low-E glass to increase heat resistance. With a U-value of 0.04, EPS is one of the most effective insulation materials, and it reduces the envelope thermal conductivity to 1.07 and 0.75 W/ m^2·k, on the wall and roof respectively. Double-layered Low-E glass has a combined thermal conductivity of 2.5 W/ m^2·k, compared to 6.0 of traditional glass. Table 4 shows the material composition of "Extended Insulation".

Table 3: "Traditional Insulation"

Wall Composition, U=3.23

No	Layer Name	Width	Density	Sp. Heat	U
1	Ceramic Tiles	0.010	2.40	840	1.30
2	Cement Mortar	0.015	2.00	800	1.50
3	Reinforced Concrete	0.150	2.20	880	1.40
4	Cement Mortar	0.010	2.00	800	1.50

Roof Composition, U=1.00

No	Layer Name	Width	Density	Sp. Heat	U
1	Cement five-leg tile	0.050	0.70	900	1.50
2	Polystyrene Foam	0.020	1.04	1130	0.04
3	Concrete Lightweight	0.050	0.95	656.9	0.80
4	Asphaltic Felt	0.010	1.02	900	0.11
5	Cement Mortar	0.020	2.00	800	1.50
6	Reinforced Concrete	0.150	2.20	880	1.40
7	Cement Mortar	0.015	2.000	800	1.50

Traditional Glass, U=6.0

No	Layer Name	Width	Density	Sp. Heat	U
1	Glass Standard	0.006	2.30	836.8	1.05

Table 4: "Extended Insulation"

Wall Composition, U=1.07

No	Layer Name	Width	Density	Sp. Heat	U
1	Ceramic Tiles	0.010	2.40	840	1.30
	EPS	0.025	21.04	1300	0.04
2	Cement Mortar	0.015	2.00	800	1.50
3	Reinforced Concrete	0.150	2.20	880	1.40
5	Cement Mortar	0.010	2.00	800	1.50

Roof Composition, U=0.75

No	Layer Name	Width	Density	Sp. Heat	U
1	Concrete 1-4 Dry	0.050	2.30	800	1.40
2	PU Block	0.025	1.05	1250	0.028
3	PU	0.005	1.05	1250	0.05
4	Cement Mortar	0.015	2.00	800	1.50
5	Reinforced Concrete	0.150	2.20	880	1.40
6	Cement Mortar	0.015	2000.0	800	1.50

Low-E Glass, U=2.50

No	Layer Name	Width	Density	Sp. Heat	U
1	Glass Standard	0.006	2300.0	836.800	1.046
2	Air Gap	0.030	1.3	1004.00	5.560
3	Glass Standard	0.006	2300.0	836.800	1.046

3. RESEARCH RESULTS

A. Annual Energy Consumption

After a series of simulation, annual energy consumption of the two types of residential buildings is listed in Table 5, 6, 7, and 8.

Table 5: Annual Energy Consumption(KWH), 5-Story House, Facing West

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	68,879.17	81,434.48*	38,745.79	48,331.52
Taichung	77,094.65	92,917.36	42,109.52	56,010.93
Kaohsiung	98,015.24	118,164.58	53,881.35	70,411.45

*Baseline

Table 6: Annual Energy Consumption(KWH), 5-Story House, Facing North

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	68,059.13	78,978.82*	37,757.78	45,650.81
Taichung	75,902.02	89,117.29	40,827.71	52,038.93
Kaohsiung	96,717.30	114,543.31	52,460.78	66,643.06

*Baseline

Table 7: Annual Energy Consumption(KWH), 12-Story Condominium, Facing West

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	287,970.94	357,222.50*	184,184.72	222,238.40
Taichung	323,584.38	410,404.90	190,285.38	258,618.91
Kaohsiung	401,207.81	506,015.62	236,623.65	306,444.61

*Baseline

Table 8: Annual Energy Consumption (KWH), 12-Story Condominium, Facing North

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	286,335.81	351,622.05	182,175.39	216,380.24
Taichung	320,017.95	399,040.54	186,811.36	247,091.92
Kaohsiung	398,511.36	497,345.66	234,554.69	297,598.66

*Baseline

From the 4 tables, the research team has concluded the following:

1. Insulation effect: annual energy saving from 13.83.4% to 21.15% achieved

	5-story, facing West	5-story, facing North	12-story, facing West	12-story, facing North
Taipei	15.42%	13.83%	19.39%	18.57%
Taichung	17.03%	14.83%	21.15%	19.80%
Kaohsiung	17.05%	15.56%	20.71%	19.87%

2. Airtight effect: annual energy saving from 36.98% to 42.20% achieved

	5-story, facing West	5-story, facing North	12-story, facing West	12-story, facing North
Taipei	40.65%	42.20%	37.79%	38.46%
Taichung	39.72%	41.61%	36.98%	38.08%
Kaohsiung	40.41%	41.82%	39.44%	40.16%

3 Insulation + airtight effect: annual energy saving from 48.19% to 54.68% achieved

	5-story, facing West	5-story, facing North	12-story, facing West	12-story, facing North
Taipei	52.42%	52.19%	48.44%	48.19%
Taichung	54.68%	54.19%	53.63%	53.18%
Kaohsiung	54.40%	54.20%	53.24%	52.84%

4. Orientation effect: “Facing West” results in 1.57%(12-story) to 3.02%(5-story) energy increase

5. Location effect: Kaohsiung, with tropical climate feature, requires 45% more annual energy than Taipei. Taichung requires 14% more annual energy than Taipei.

6. Building type effect: Using baseline data as example, 12-story condominium can achieve almost 10% energy saving per unit area, and 60% saving per capita.

	Energy/m2	Energy/family	Energy/capita
5-story, facing West	102.52 KWH	40717.24 KWH	6786.21 KWH
5-story, facing North	99.43 KWH	39489.41 KWH	6581.57 KWH
12-story, facing West	92.43 KWH	16237.39 KWH	4059.35 KWH
12-story, facing North	90.98 KWH	15982.82 KWH	3995.71 KWH

B. Room Temperature

The temperature is estimated when the following conditions are set:

(1) Temperature is measured on 2nd floor of the building.

(2) Temperature is measured based on the weather condition of 2:00PM, July, 22nd. July, 22nd is called Da-Su (meaning “big hot”) in Chinese Lunar calendar, which is statistically the hottest day of a year.

(3) Temperature is measured when all air conditioning is turned off, but all equipment/device is operated as normal.

Table 9 through Table 12 show room temperature simulation results. Without air conditioning, airtightness raises room temperature about 0.5 ℃, while insulation alone seems not making noticeable difference. However, It is observed that with both extended insulation and enhanced airtightness, room temperature can be raise at most 3.2℃.

Table 9: Room Temperature(℃): Double Unit - 5-Story House, Facing West

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	31.4	31.4*	34.1	32.0
Taichung	27.9	28.2	30.8	29.0
Kaohsiung	28.3	28.5	30.8	29.0

Table 10: Room Temperature(℃): Double Unit - 5-Story House, Facing North

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	31.4	31.2*	34.0	31.8
Taichung	27.9	27.9	30.7	28.7
Kaohsiung	28.3	28.3	30.8	28.8

Table 11: Room Temperature(℃):12-Story Condominium, Facing West

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	31.5	31.5*	34.7	32.2
Taichung	27.9	28.2	31.3	29.3
Kaohsiung	28.4	28.7	31.4	29.4

Table 12: Room Temperature(℃):12-Story Condominium, Facing North

	Air Leak(3.25ach)		Air Tight(0.5ach)	
	Ext. Insulation	Trad. Insulation	Ext. Insulation	Trad. Insulation
Taipei	31.5	31.7*	34.7	32.5
Taichung	28.0	28.5	31.4	29.6
Kaohsiung	28.4	28.9	31.5	29.6

4. CONCLUSIONS

After the analysis, this research has drawn the following conclusions:

(1) Both extended insulation and better airtightness can drastically reduce energy consumption, while airtightness is more effective than insulation.

(2) Buildings facing west always consumes more energy than building facing north

(3) Location wise, buildings in Kaohsiung are less energy-effective.

(4) Airtightness raises room temperature.

During the simulation sessions, the research team has also found that basic assumptions such as window open/close, number of occupants, and internal loading are also key factors that can impact room temperature and energy consumption. The research has demonstrated that Ecotect Analysis® is an effective communication tool in a preliminary design stage, and Ecotect Analysis® has great potential to help designers in delivering building projects with sustainable innovation.

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FUNCTION REQUIREMENTS OF BIM-BASED COLLABORATIVE WORK PLATFORM SUPPORTING IPD PROJECTS

Zhiliang Ma
Dept. of Civil Eng. Tsinghua University, Beijing, P.R. China, mazl@tsinghua.edu.cn

Jiankun Ma
Dept. of Civil Eng. Tsinghua University, Beijing, P.R. China, majiankun2011@gmail.com

Abstract

IPD (Integrated Project Delivery) is a new project delivery mode and its main characteristic is that all participants join the project early to work collaboratively, in order to maximize the overall merit of the project. Thus the collaborative work among the participants in IPD projects is of special importance. BIM (Building Information Modeling) technology has played an important role in IPD projects. To help multiple participants and specialties collaborate more efficiently based on BIM technology, it is necessary to use a collaborative work platform.

In order to facilitate the development of a dedicated platform, this paper aims to establish the application function requirements on the platform by analyzing existing IPD reports and IPD cases. Firstly, the use cases of how the IPD project participants and specialties collaborate are summarized. Secondly, based on the use cases, the application function requirements are identified. Then existing collaborative work platforms are examined against the requirements to verify the necessity for developing the dedicated platform. Finally the total function requirements on the platform which incorporate the service function requirements are formulated to facilitate the development of the platform.

Keywords: BIM, collaborative work, collaborative work platform, function requirements, IPD.

1. INTRODUCTION

Integrated Project Delivery (IPD for short hereafter) is a new project delivery mode emerged in the construction industry of the Europe and the United States and so on, and its main characteristic is that the structural designer, MEP designer, HAVC designer, contractor and manufacturer, etc. join early in the project to work with the owner and the architect collaboratively, in order to reduce re-work and waste and improve the overall merit of the project by considering the demand of each phases, such as the construction phase, which follow the design phase (AIA 2007; Mounir et al. 2012; Fawaz et al. 2012). Thus it is clear that the collaborative work among the participants and specialties in an IPD project is of special importance, and the efficiency and quality of collaborative work affect the realization of the merits of IPD projects directly.

As an emerging technology, Building Information Modeling (BIM for short hereafter) technology has played an important role in architectural design, structural design, MEP design and HAVC design respectively in IPD projects (Leentje 2010). In order to make the multiple participants and specialties collaborate more efficiently based on BIM technology, it is necessary to use a collaborative work platform. According to the reports about IPD, some IPD projects have used existing collaborative work platforms to manage document and conduct video conferences (AIA 2010 and 2011; ACA 2013; DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011). Xue analyzed the previous papers about collaborative work platform, which are published from 2001 to 2011 and found that there is no research about collaborative work platform which is based on BIM technology and specially designed for IPD projects (Xue et al. 2012). But there have already been some researches on BIM-based collaborative work platform supporting construction projects. Through questionnaire survey and case study, Singh summarized the service functions which a BIM-based collaborative work platform should provide to support construction projects (Singh et al. 2011). In addition, the study of BIM Server is of the same kind. Helm realized conflict detection of BIM model based on BIM Server (Helm et al. 2010). Rinka carried out building physical simulation with BIM Server (Rinka 2013). Berlo, Laat and Hijazi integrated BIM Server and GIS (Berlo and Laat 2011; Hijazi et al. 2011). Cahill used a BIM Server to do facility management and building operation (Cahill et al. 2012). Considering the necessity of BIM technology application in IPD projects and the importance of collaboration in IPD projects, it can be inferred that a collaborative work platform which facilitates BIM technology to be applied in IPD projects can support the IPD project more efficiently.

To develop a dedicated platform, it is necessary to carry out requirement analysis and system design, and this paper focuses on the former, i.e. the requirement analysis. Generally, the major part of the requirement analysis in software development is the function requirement analysis which contains application function requirements and service function requirements. This paper aims to establish the application function requirements on BIM-based collaborative work platform supporting IPD projects based on existing IPD reports and IPD cases. For this purpose, the use cases of how the IPD project participants collaborate are summarized firstly by analyzing IPD reports and IPD cases. Secondly, based on the use cases for collaborative work in IPD projects, the application function requirements, which represent the in-depth requirements, are identified. Then the existing collaborative work platforms are checked to find in what degree they can satisfy the application function requirements of IPD projects so as to verify the necessity for developing a BIM-based collaborative work platform supporting IPD projects. Finally the total function requirements, which incorporate the existing service function requirements on the BIM-based collaborative work platform supporting IPD projects, are formulated to facilitate the development of the platform.

2. CHARACTERISTICS OF THE COLLECTED IPD CASES AND IPD REPORTS

In order to make the platform be applicable to various IPD projects, we have tried our best to collect as many IPD reports and IPD cases as possible to identify the function requirements of IPD projects on the collaborative work platform. For this purpose, 64 IPD cases and 7 IPD reports are finally collected by downloading IPD information from the official website of the organizations that have discussed the issue of IPD, by identifying IPD case information from literatures that are related to IPD, and by requesting IPD information through email. The IPD cases that were obtained include 21 IPD cases executed in the United States from 2003 to 2011, 28 IPD cases executed in the United Kingdom from 2000 to 2010, 14 IPD cases executed in Australia from 2001 to 2011, and 1 IPD case executed in China in 2011 (AIA 2010 and 2011; ACA 2013; DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011; Yang et al. 2012). In the IPD cases, 77% of the cases used BIM technology, and all the cases used some collaborative work platform. The other characteristics of the IPD cases are shown in Figure 1. The IPD reports that were collected include 6 IPD reports which were published independently by the AIA (American Institute of Architects), the AGC (Associated General Contractors of America), the CMAA (Construction Management Association of America), the ACA (Association of Consultant Architects) in the United Kingdom and the DTF (Department of Treasury and Finance) in Australia, and a IPD report published jointly by the NASFA (National Association of State Facilities Administrators), the COAA (Construction Owners Association of America), the APPA (Association of Higher Education Facilities Officers), the AGC and the AIA (AIA 2007; AGC 2007; CMAA 2010; ACA 2010; DTF 2010a and 2010b; Kenig et al. 2013), and all the reports are guides for applying IPD.

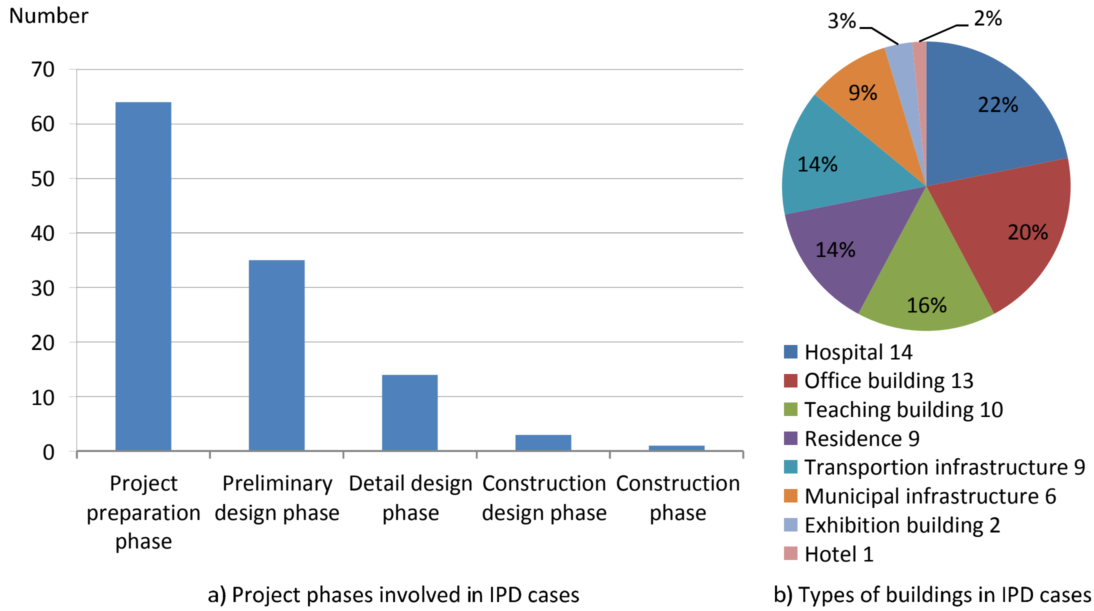

Figure 1: Some characteristics of the IPD cases

3. USE CASES FOR COLLABORATIVE WORK IN IPD PROJECTS

Index	Use case for collaborative work	Brief description of how participants work	Project phase containing the work	Source
A1	Analyze function requirements of building	Owner and architect analyze jointly	Project preparation phase	Report (AIA 2007; DTF 2010)
A2	Determine design criteria for each specialty	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; DTF 2010)
A3	Determine standard for exchanging BIM data	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; DTF 2010; Kenig et al. 2013) & case (AIA 2010 and 2011; DTF 2012; Chuck et al. 2011)
A4	Select architectural conceptual design	Owner and architect select jointly	Project preparation phase	Case (Ku 2009; Chuck et al. 2011)
A5	Determine major works for each project phase	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; AGC 2007; Kenig et al. 2013)
A6	Determine time control points for project	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; DTF 2010) & case (Reza 2011; Nofera et al. 2011; Chuck et al. 2011)
A7	Determine reciprocal responsibility of participants	All participants negotiate jointly	Project preparation phase	Report (AIA 2007) & case (DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
A8	Determine how to allocate benefit and risk	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; AGC 2007; CMAA 2010; DTF 2010a and 2010b) & case (DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
A9	Establish mechanism of conflict coordination	All participants negotiate jointly	Project preparation phase	Report (AIA 2007; AGC 2007; CMAA 2010; ACA 2010; DTF 2010a and 2010b; Kenig et al. 2013) & case (AIA 2010 and 2011; ACA 2013; DTF 2012)
A10	Select structure type of building	Structural engineer and architect select jointly	Construction design phase	Report (AIA 2007; AGC 2007; ACA 2010; DTF 2010a and 2010b) & case (Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
A11	Answer questions about prefabricating constructional elements	Related designers explain the design intent to manufacturer	Construction phase	Report (CMAA 2010; ACA 2010; DTF 2010a and 2010b; Kenig et al. 2013)
A12	Answer questions when constructing	Related designers explain the design intent to contractor	Construction phase	Report (AGC 2007; CMAA 2010; ACA 2010; DTF 2010a and 2010b; Kenig et al. 2013) & case (Kihong et al. 2009)

Table 1: Use case for synchronous collaborative work in IPD projects

Typical use cases for collaborative work reflected in IPD cases and IPD reports are summarized respectively. Because major use cases for collaborative work are narrated in each IPD reports which were collected in this study, this paper identifies a use case as a use case for collaborative work only if it involves multiple participants or multiple specialties. For IPD cases, a use case for collaborative work is also extracted if it involves multiple participants or multiple specialties. In the process of extracting use case for collaborative work from IPD cases, in order to make the use case for collaborative work have the same granularity, the following principle, i.e. a single deliverable as stipulated in a IPD standard contract will be obtained through each use case for collaborative work, was also satisfied. For example, in an IPD project where an exhibition building was constructed, a use case, in which the architect who cares aesthetics of architecture and use function more and the structural engineering who cares technical feasibility and cost saving select the structure type of the building jointly and at last they reached an agreement on a balanced scheme, is identified as a use case for collaborative work. Then the use cases for collaborative work identified in accordance with the above principles are divided into use case for synchronous collaborative work and use case for asynchronous collaborative work, and are listed in Table 1 and Table 2 respectively in the chronological order in which they normally happen. The Synchronous collaborative work, which corresponds to face-to-face negotiation or discussion, means that collaborative work needs to be done synchronously by multiple participants or specialties who are in charge of it, and in contrast the asynchronous collaborative work means that collaborative work does not need to be done synchronously by participants or specialties who are in charge of it.

Index	Use case for collaborative work	Brief description of how participants work	Project phase containing the work	Source
B1	Make a schedule of design phase	The architect makes a schedule, and then all participants examine it jointly.	Preliminary design phase	Report (AIA 2007; DTF 2010a and 2010b; Kenig et al. 2013) & case (AIA 2010 and 2011; ACA 2013; DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
B2	Complete site design	The architect completes a site design, and then all participants examine it jointly.	Preliminary design phase	Report (DTF 2010a and 2010b) & case (DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
B3	Complete pipeline design of site	The MEP designer completes a pipeline design of site, and then detects its conflicts with architect.	Preliminary design phase	Report (AIA 2007; AGC 2007; CMAA 2010; ACA 2010; DTF 2010a and 2010b; Kenig et al. 2013) & case (Nofera et al. 2011; Kim et al. 2009)
B4	Complete architectural schematic design	The architect completes an architectural schematic design, and then all participants examine it jointly.	Preliminary design phase	Report (AIA 2007; AGC 2007; CMAA 2010; Kenig et al. 2013) & case (AIA 2010 and 2011; DTF 2012; Chuck et al. 2011)
B5	Completed preliminary technical design	Specialties complete preliminary technical design separately, then they detect its conflicts with the architect, and finally they extract partial model from BIM model separately.	Detail design phase	Report (AIA 2007; AGC 2007; CMAA 2010; DTF 2010a and 2010b; Kenig et al. 2013) & case (AIA 2010 and 2011; ACA 2013; DTF 2012; Reza 2011; Nofera et al. 2011; Kihong et al. 2009; Kim et al. 2009; Chuck et al. 2011)
B6	Complete detailed technical design	Specialties complete detailed technical design separately, and then they detect its conflicts with the architect.	Detail design phase	Report (AIA 2007; AGC 2007; CMAA 2010; Kenig et al. 2013) & case (DTF 2012; Reza 2011; Chuck et al. 2011)
B7	Complete construction drawing design	The design team export drawings from BIM model, and then all participants examine them jointly.	Construction design phase	Report (CMAA 2010; ACA 2010; DTF 2010a; Kenig et al. 2013) & case (Kihong et al. 2009)

Table 2: Use case for Asynchronous collaborative work in IPD projects

4. APPLICATION FUNCTIONS FOR BIM-BASED COLLABORATIVE WORK PLATFORM FOR IPD PROJECTS

Based on the analysis of the use case for collaborative work listed in the above tables, it is found that the information, which is used by participants when they collaborate in IPD projects, can be divided into 4 categories, i.e. engineering document, BIM model, engineering drawing, and audiovisual information. Each use case for collaborative work is composed of activities that the participants or specialties deal with major engineering information related to the IPD project, so BIM-based collaborative work platform should have corresponding application functions to help the participants or specialties deal with major engineering information efficiently. Therefore, based on IPD cases and IPD reports, 14 patterns of how participants deal with major engineering information when they collaborate in an IPD project are summarized in Table 3. By the way, these patterns are summarized only by using the existing collaborative work platforms.

Index	Engineering document	BIM model	Engineering drawing	Audiovisual information
A1	Upload, browse, annotate			Online conference
A2	Upload, browse, annotate			Online conference
A3	Upload, browse, annotate			Online conference
A4		Upload, browse, annotate		Online conference
A5	Upload, browse, annotate			Online conference
A6	Upload, browse, annotate			Online conference
A7	Upload, browse, annotate			Online conference
A8	Upload, browse, annotate			Online conference
A9	Upload, browse, annotate			Online conference
A10		Upload, browse, extract		Online conference
A11		Browse	Browse	Online conference
A12		Browse	Browse	Online conference
B1	Upload, browse, annotate			
B2		Upload, browse, annotate		
B3		Upload, integrate, detect conflicts		
B4		Upload, browse, annotate		
B5		Upload, integrate, detect conflicts, extract, download		
B6		Upload, integrate, detect conflicts		
B7		Browse, export drawings	Browse, annotate	

Table 3: Patterns of how participants deal with engineering information when collaborating

In addition to support the patterns listed in Table 3, further application function requirements, which are also stated in the IPD cases as special requests from the project participants, are summarized in the following:

(1) Operating engineering files, such as uploading and downloading files, directly and frequently bores the participants, so they want the collaborative work platform to provide the workflow function, so that they can focus their attention on the work which they are in charge of (DTF 2012; Reza 2011;Kihong et al. 2009; Kim et al. 2009).

(2) In IPD cases, none of the project participants likes to switch between a collaborative work platform and application software frequently, thus they hope to have the ability of editing engineering documents online, or even modifying BIM model online (Kihong et al. 2009; Chuck et al. 2011).

(3) The project participants also hope that they can hold a video conference and jointly edit documents online at the same time, while they are doing the design review of a BIM model which is mainly composed of browsing and annotating the BIM model (AIA 2010 and 2011; Kihong et al. 2009; Chuck et al. 2011).

(4) The design team of IPD projects want to use multiple windows to browse BIM model from multiple perspectives at the same time, which is like what a stand-alone design software application does, when they review the BIM model of IPD project (DTF 2012; Fish and Amanda 2011).

(5) Structure designer, MEP designer and HAVC designer, etc. in IPD projects request to determine what to be extracted from BIM model by themselves, because the current pattern that third parties predefines what to be extracted from BIM model cannot satisfy the requirements of multiple participants collaborating in design phase completely (Reza 2011; Chuck et al. 2011; Leonidas 2010).

In addition, one of the authors introduced the connection between engineering documents and engineering drawings on a collaborative work platform (Ma et al. 2004, 2005 and 2008), and since engineering drawings can be generated from BIM models in IPD projects, if an engineering document is used to illustrate BIM models and engineering drawings, engineering documents, engineering drawings and BIM models should be connected to each other too. When the BIM model is modified, engineering drawings should be updated automatically without being exported again. The requirement of displaying engineering information on multiple windows synchronously in IPD projects implies an upgraded requirement of displaying engineering information on multiple screens synchronously. Based on the above analysis, 23 application function requirements of IPD projects on BIM-based collaborative work platform are identified as shown in Table 4. They can be divided into 4 categories, i.e. document related requirements, BIM model related requirements, drawing related requirements, and comprehensive requirements. According to the author's experience of developing software and knowledge of information technology used in developing a collaborative work platform, all the requirements listed in table 4 can be are realized.

Category	Index	Function requirement	Category	Index	Function requirement
Document related requirements	1	Upload document	Drawing related requirements	14	Export drawings from BIM model
	2	Browse document		15	Browse drawings
	3	Annotate document		16	Annotate drawings
	4	Edit document online		17	Update drawings automatically when BIM model is modified
BIM model related requirements	5	Upload BIM model	Comprehensive requirements	18	Hold video conference
	6	Browse BIM model		19	Hold video conference and edit document when review BIM model
	7	Annotate BIM model		20	Connect document, drawing and BIM model to each other
	8	Integrate BIM model		21	Display engineering information on multiple windows synchronous
	9	Detect conflicts of BIM model		22	Display engineering information on multiple screens synchronous
	10	Edit BIM model online		23	Execute workflow automatically
	11	Extract predefined content from BIM model			
	12	Extract user-defined content from BIM model			
	13	Download BIM model			

Table 4: Application function requirements of IPD project on collaborative work platform

5. VERIFICATION OF EXISTING COLLABORATIVE WORK PLATFORMS FOR APPLICATION FUNCTION REQUIREMENTS

Four commercial collaborative work platforms which include Bentley Projectwise, GotoMeeting, WebEX and Smartboard have been applied in the IPD cases. In addition, Eastman briefly analyzed seven collaborative work platforms which include Bently Projectwise, Graghisoft BIMserver, Open BIMserver, Autodesk Revit Server, Autodesk Vault, Adobe connect and Autodesk Buzzsaw and can help participants apply BIM technology in construction projects (Chuck 2011). In this paper, the 10 commercial collaborative work platforms mentioned above were examined as typical collaborative work platforms supporting construction projects to find out in what extent these typical collaborative work platforms satisfy the application function requirements of IPD projects. The result is shown in Table 6.

Collaborative work platform / Function requirement	Graghisoft BIMserver	Open BIMserver	Bently Projectwise	Autodesk Revit Server	Autodesk Vault	GotoMeeting	WebEX	Smartboard	Adobe connect	Autodesk Buzzsaw
1			√			√	√	√	√	√
2			√			√	√	√	√	√
3			√			√	√	√	√	√
4									√	
5	√	√	√	√	√			√		√
6	√	√	√	√	√			√		√
7			√					√		√
8	√	√		√	√					√
9		√								
10	√			√						
11	√	√		√	√					√
12										
13	√	√	√	√	√			√		√
14	√			√	√					
15	√		√	√	√	√	√		√	√
16			√			√	√		√	√
17				√						
18						√	√	√	√	
19										
20										
21	√									
22										
23										
Total number	9	6	9	9	7	6	6	8	7	11

Table 6: Extent of collaborative work platforms satisfying application function requirements of IPD projects

As indicated in Table 6, none of the 10 existing collaborative work platforms can provide all the 23 application functions, and the one which can offer 48% of the 23 application functions is the best. By doing thought experiments, it can be inferred that if the project participants were provided with all the 23 application functions, they would have executed IPD projects more effectively and more efficiently. This verifies the necessity of developing a BIM-based collaborative work platform supporting IPD projects.

6. TOTAL FUNCTION REQUIREMENTS ON BIM-BASED COLLABORATIVE WORK PLATFORM SUPPORTING IPD PROJECTS

As mentioned earlier, the total function requirements on BIM-based collaborative work platforms supporting IPD projects contain application function requirements and service function requirements. Through questionnaire survey and case study, Singh divided the service functions that BIM-based collaborative work platform should provide into 6 major categories, i.e. BIM model storage management, BIM model access, BIM model user interface, system operation maintenance, data security and user help (Singh et al. 2011). Because these service function requirements are applicable to all collaborative platforms, they can also be applied in BIM-based collaborative work platforms supporting IPD projects. Thus, the total function requirements on BIM-based collaborative work platform for IPD projects is consisted of the application function requirements which is identified by this paper in the above, and the service function requirements of general project which is summarized by Singh.

7. CONCLUSIONS

Based on the IPD reports and IPD cases collected from literatures and websites, the application function requirements on BIM-based collaborative work platform supporting IPD projects are identified in this paper, and the total function requirements of IPD project on the platform are formulated by combining with previous research results. This paper lays a sound foundation for the development of BIM-based collaborative work platform which supports IPD project specially.

ACKNOWLEDGMENTS

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INTEGRATED BUILDING INFORMATION MODELLING (BIM) WITH SUPPLY CHAIN AND FEED-FORWARD CONTROL

Mojtaba Maghrebi
University of New South Wales, Sydney, Australia, maghrebi@unsw.edu.au

Travis Waller
University of New South Wales, Sydney, Australia, s.waller@unsw.edu.au

Claude Sammut
University of New South Wales, Sydney, Australia, claude@cse.unsw.edu.au

Abstract

One of the major causes of delays in construction sites belongs to the delays in delivering materials. This paper introduces the integrated Building Information Modeling (BIM) model combined with a supply chain and a controlling system, along with its efficiency for alleviating the negative effects of delays caused by a lack of materials on construction sites. So, firstly the concept of feed-forward control is discussed as a prevention feature in a monitoring system. Then the integrating BIM model with a supply chain is introduced. Finally this case study has shown how the enhanced BIM model can incorporate the feed-forward control in order to decrease the risks of delays caused by a lack of materials in construction. Moreover, this case study might be used as a decision support system for managers to prevent a construction site from future delays by providing valuable information about the required materials in advanced.

Keywords: building information modeling, supply chain, feed-forward control

1. INTRODUCTION

In terms of producing a product it can be said that a construction site is very similar to a factory. In a production line raw materials arrive at a workspace and after performing some tasks, the final production leaves the workspace. In a similar fashion construction sites add value to the raw materials during the operation process. So, the success of a construction project is very dependent on its supplied materials. This paper focuses on the supply chain process and the possible delays caused by a lack of materials on construction sites.

On the other hand, keeping the execution project on track on a construction site is an important goal for construction managers. As it was discussed before any delays in the supply process will lead to a decrease in the productivity rate during construction. Therefore, knowing about the reliability of a supply chain plan might help managers to make better decisions in advanced, which in some cases can possibly prevent the operation process from worse outcomes. The managers need sufficient information for each decision also implementing an automated system that will be able to alert the unexpected events may possibly decrease the managerial risks in construction.

One of the most significant characteristics of BIM is that it can provide the required information in an organized pattern. BIM tries to establish a comprehensive data-base from all constructional components. However, BIM initially only concentrates on gathering the required data for the execution process and in the literature there are only a few research papers that is regarding the enhancement of BIM with a supply chain (Sacks et al., 2010b, Taylor and Bernstein, 2009). However in literature it has not been clearly addressed how the efficiency of a supply chain can be increased in an automated fashion. This issue becomes more crucial for critical components where a delay in the supply chain will cause a delay in the whole construction process. In this paper we are introducing a platform for integrating supply chain disciplines with BIM in order to decrease the construction delays caused by lack of materials. Moreover, in order to inform the managers in advanced about undesired issues in the supply chain, the concept of feed-forward control in cooperation with the enhanced BIM model is used.

In this paper firstly the concept of feed-forward control in construction is comprehensively discussed, secondly the BIM and conducted research in this area is reviewed. Then the proposed model for integrating BIM with supply chain is introduced and is tested in the case study. Subsequently the impacts of the introduced model and its possibilities in construction are discussed in the conclusion.

2. FEED-FORWARD CONTROL

In traditional models, the control and planning process are based on feedback information. It means that after an operational process the acquired information is sent to the control and planning stage, in this stage the actual characteristics of the project is compared with expected specifications. If the project is behind the desired goal then some adjustment actions will be made by authorized people to get the project back on track (Figure 1).

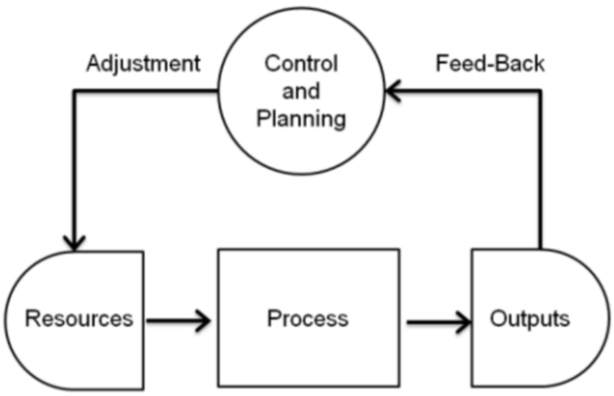

Figure 1: Traditional Process Planning and Control Model

In the proposed control model (Figure 2) the resources should be assessed, before any activity, in the compatibility checking stage. The results of this assessment will be sent to the control stage by a feed-forward flow. This process reflects the actual circumstances in the supply chain. In the control stage the results of compatibility is compared with the expected outcomes which were embedded in the BIM. If there is any gap with these two, an adjustment action is required that must be applied in the BIM and via the BIM the resources will be revised. Furthermore, during the operation process the project will be monitored for controlling purposes. At the end of the operation process the project`s outputs will also be evaluated and if there is any gap between the ideal output and the actual output, again the information will be sent to the control stage for further analysis and for possible replanning.

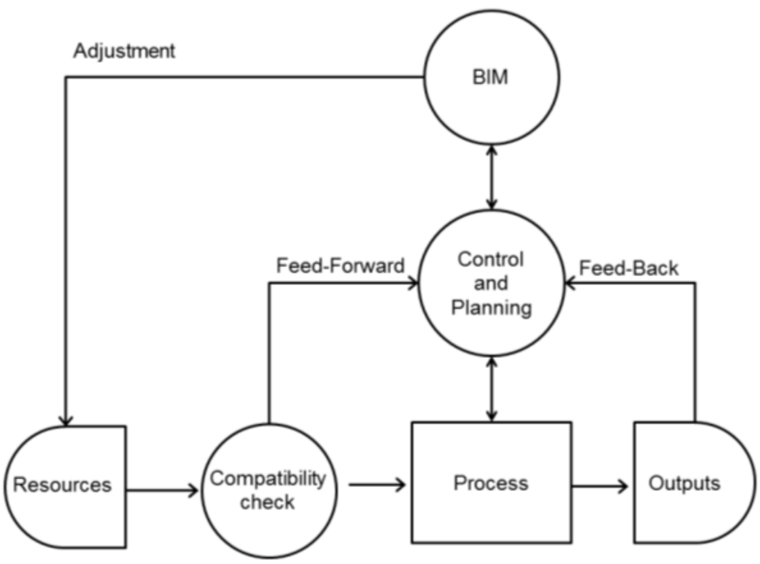

Figure 2: Process Control model

In this paper the introduced controlling model is used to identify the possible challenges as early as possible. The mangers will potentially have enough time to find a way to solve the highlighted problems because these circumstances defiantly are better than the situations that they just faced with problem. However the introduced controlling model needs to be fed the updated information at each moment.

3. BUILDING INFORMATION MODELLING (BIM)

The concept of BIM was coined by Charles M. Eastman at Georgia Tech (Eastman et al., 2008) and from 1970s he has worked on an extension of the BIM. His main research focuses on product modeling, data modeling and information modeling in engineering (Eastman et al., 1991, Eastman et al., 1993, Eastman, 1994, Eastman and Siabiris, 1995, Khedro et al., 1996, Eastman et al., 2003, Eastman et al., 2005, Lee et al., 2006, Lee et al., 2010a, Lee et al., 2010b, Sacks et al., 2010a). The concept of Building Information Modeling means building a building virtually prior to building it physically, in order to work out problems, and simulate and analyze potential impacts (Smith and Tardif, 2009). BIM is an object-oriented data-base which covers attributes and roles of all construction components. Moreover, BIM can be used as a tool for generating and managing data during the life cycle of structures. BIM covers building geometry, spatial relationships, geographic information, and quantities and properties of building components (Eastman et al., 2011, Elvin, 2007, Underwood and Isikdag, 2009, Kymmell, 2008, Smith and Tardif, 2009, Lee et al., 2006). Meadati (2007) (Meadati, 2007) expresses that BIM is only used at an early stage and tries to integrate BIM by the 3D as-built model to increase the capability of BIM during the maintenance period. In terms of automation in BIM, several scholars have worked on this area, and mostly, accuracy and reliability of the model were the main concerns (Lee et al., 2010a). Translation of design to a computational form were studied by several scholars such as (Yang and Xu, 2004, Elvin, 2007). Grilo (2010) (Grilo and Jardim-Goncalves, 2010)expresses that a large amount of data is gathered by BIM but the access to this data-base is not facilitated then he attempted to improve the interoperability of data in a construction project during its lifetime by the standardization of the shared data. As it was discussed before, most of research in BIM was devoted to the design and execution process and this issue were addressed in the literature specially in the review papers of Succar(Succar, 2009). However, in this paper it is focused on integrating BIM with a supply chain and its application in construction. BIM is hired in this paper as the core of the information in providing the required information to the authorized people involved in the construction process. Then an enhanced BIM with a supply chain is used with a feed-forward control in order to decrease the negative effects of delays caused by a lack of materials in construction.

4. METHODOLOGY

It is expected that by implementing the proposed controlling model (Figure 1) and the feed-forward controls the problems in the supply chain can be automatically detected upfront. So, first of all the BIM needs to be enhanced with a supply chain. For this purpose the proposed model is depicted in (Figure3). BIM is an objected oriented database and information can be added to BIM just by assigning it to the construction components. Already information about the specifications of materials, cost and time are assigned to components. Now the supply chain properties can be assigned to the components. BIM supply chain contains essential information from the entire the supply process for example from the end of the design process when the required materials are defined till to the date that is expected from suppliers to deliver the materials to the site. The whole of this process is illustrated at the bottom of (Figure3). In other words, this information for each component is a list of milestones and time slots that were scheduled by planners to ensure that the required materials for operations would be at the site before the commencement of operations. After adding these properties to each component a 3D BIM model can be built. By having all components together, the process planning can now be added which includes the execution plan. It categorizes the components into the groups that are known as the construction tasks. All components of a task must be executed together. Other relationships between tasks such as precedence and other network relations among the tasks are defined in this stage. The last feature that must be added to the model is time. This attribute is assigned to tasks that were defined in the previous stage. Subsequently, an enhanced BIM model with a supply chain is created. Based on the other information provided the BIM model can be 4D, 5D …, and nD. Consequently, with this model producing different reports and specific plans are straightforward for planners. This paper only focuses on supply chain plans rather than other possible outputs from the model.

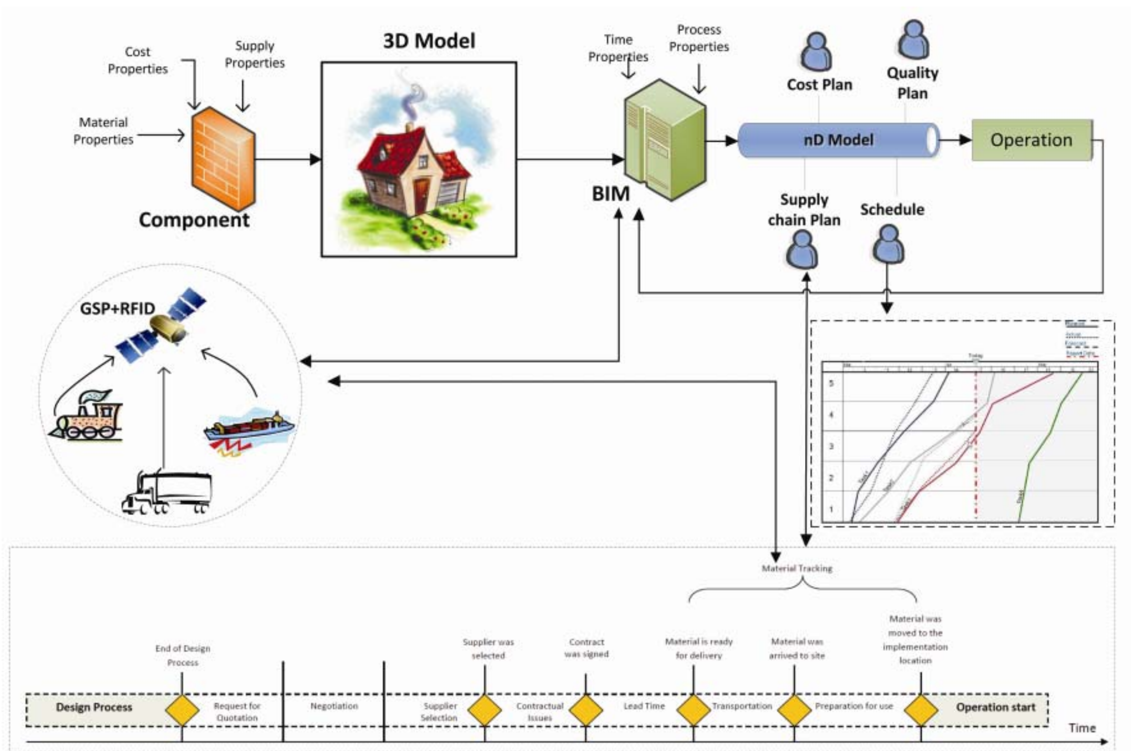

Figure 3: Proposed model for integrating BIM with supply chain

A comprehensive BIM model does not merely work in a construction project because the information in construction is very uncertain and might be changed at any time. For alleviating this dynamic behavior the concept of feed-forward control that was discussed previously can potentially reduce the possible risks of unavailable materials on construction sites for as long as it is incorporated with updated data achieved by an enhanced BIM data base.

The supply chain properties provide several milestones for each component that need to be checked at the defined dates. In practice, doing this job manually is cumbersome because there are many components in a project that are supplied from different resources and different suppliers, so, it needs to be done automatically. It should be noted that RFID and GPS can be applied in the proposed model. After checking each milestone the updated information will be controlled with the supply plan. If there is any positive or negative gap between the expected outcomes and the actual outcomes of a component, then updates will be sent to the control stage where it will be reviewed by authorized people. Sometimes delivering materials to a site sooner than the plan can be a challenge, where the storage space for raw materials is very limited. So, receiving material sooner than its planned date is usually not a desired outcome. Consequently, the materials must be on site at the scheduled date with minimum delay or sooner delivery. Taking advantage of updates regarding the materials creates opportunities for planners to adjust the operation plan under the new circumstances. This ability will possibly prevent the construction process from delays caused by unavailable materials.

5. CASE STUDY AND DISCUSSION:

In order to test the introduced model, a construction project in Sydney area was selected. The project comprises of an accommodation building with 8 stories located in a university with very limited space for storing the raw materials. Also the contractor is under pressure from university to deliver the project on time. Due to the economic considerations the concrete piles for this project were ordered from China. However, the long distance between the prefab factory in China and the construction site in Sydney is a big challenge for managers. Moreover, the critical issue is that the piles must be placed in foundation and all other construction task will be run after finishing the task. So any delay in piles delivery defiantly will lead to increasing the delays for the project. In this construction site, it wouldn’t be appropriate to have an expectation to receive the piles according to schedule. They must be certain that the pile will be delivered to the site on the exact planned dates with minimum variability. We implemented our model on this project based on the overview that is illustrated in (Figure4).

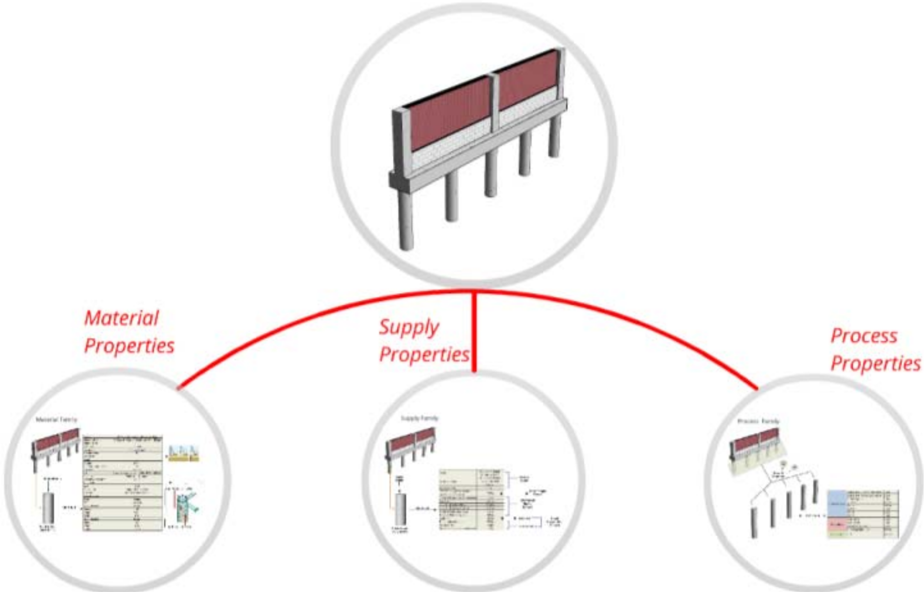

Figure 4: Overview of steps that is needed for enhancing BIM with supply chain.

Firstly, the material properties were assigned to the piles (Figure 5) which includes all required information about the sizes, geometries, and quantity of required materials. As the cost of a pile is fixed then the cost feature is embedded in the material properties and linked to the cost plan.

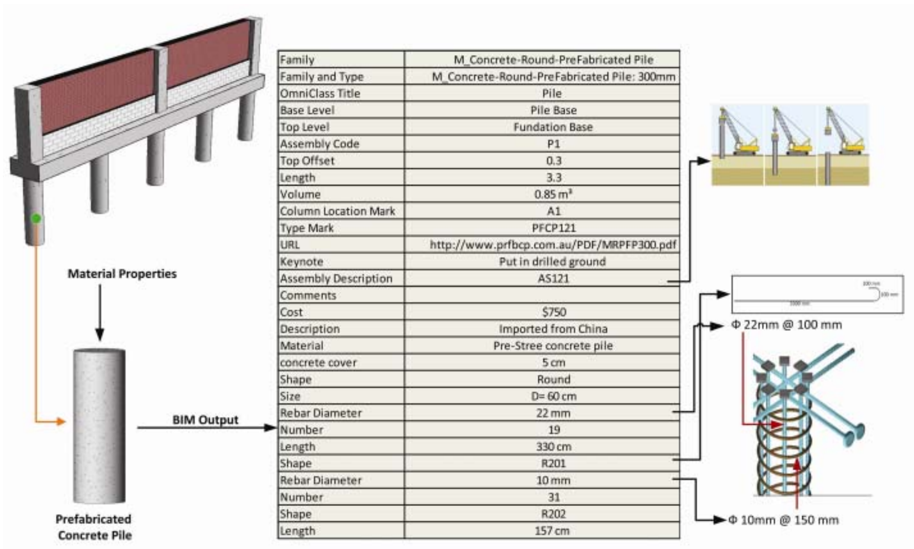

Figure 5: Structure of material properties for piles

Secondly, supply properties were defined for piles (Figure 6). All the defined periods are in the negative because they were calculated relative to the date that the construction task is in need of components. Then after adding the time properties to the tasks, the supply chain plan will be automatically calculated based on the supply properties and the given date by the time properties.

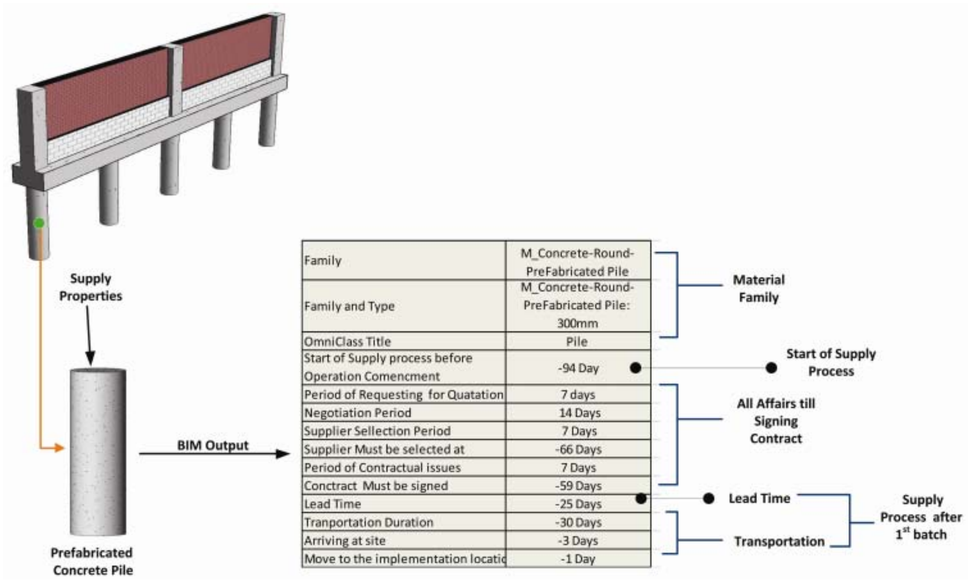

Figure6 : Structure of supply properties for piles

Finally, the process properties were set in BIM (Figure7). At this step, rather than defining the execution process, all the other required resources that were not covered in material properties are estimated and embedded in the BIM model.

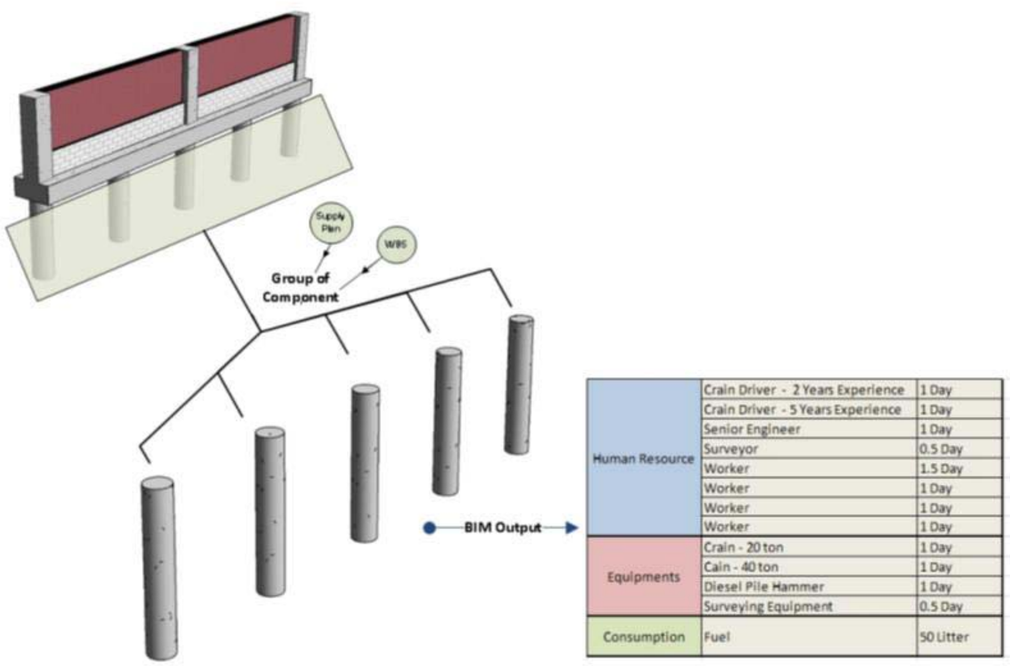

Figure 7: Structure of process properties for a set of piles

The BIM model was then enhanced with supply features. However, a well-founded data base will not merely work, since it needs to be integrated in to the planning system in order to control the supply plan. In automatically compiling the supply chain data, the importance of using RFID and GPS was suggested to the construction managers. RFID can ease the identifying process of each component and GPS provides the actual location of each component.

In this scenario, it was expected that a series of piles were to be delivered to the site on the 28th of September. However, due to the shipping period and the custom affairs it was planned to ship the piles at least one month earlier from china. In analyzing the current location of piles on the 10th of September it was realized that they will not be delivered to the site on the expected date. Studies show that in typical situations the pile will be delivered to the site with at least one weeks delay (Fi.8). At this point in time it was a serious concern for construction managers, however, they identified this problem 18 days prior to the date of delivery, so there was enough time for two major adjustments.

The first adjustment was in decreasing the negative effects of a lack of piles on site by replanning the execution process. This may include compressing the duration of the rest of the tasks or swapping the flexible tasks in a schedule to compensate for the expected delay. If compressing is to be selected, then no activity will take place on the site after the 1st of October (the task commencement date) and the site will be closed for a week. So, compressing the rest of the tasks is one opportunity for managers to keep the project on track. Conversely, if swapping within the execution plan is to be selected then the manager can start other execution processes sooner than scheduled, but with potential difficulty.

The second adjustment that managers will perform will be to revise the supply chain process, in which will help them find possible obstacles. Then it is expected that resolving these problems will assist managers to increase the reliability of the supply chain. So, this kind of supply chain control, can control the negative effects of delays caused by a lack of materials and provides valuable information for managers in advanced in order to finding the possible ways to control the unexpected events occurring on construction sites.

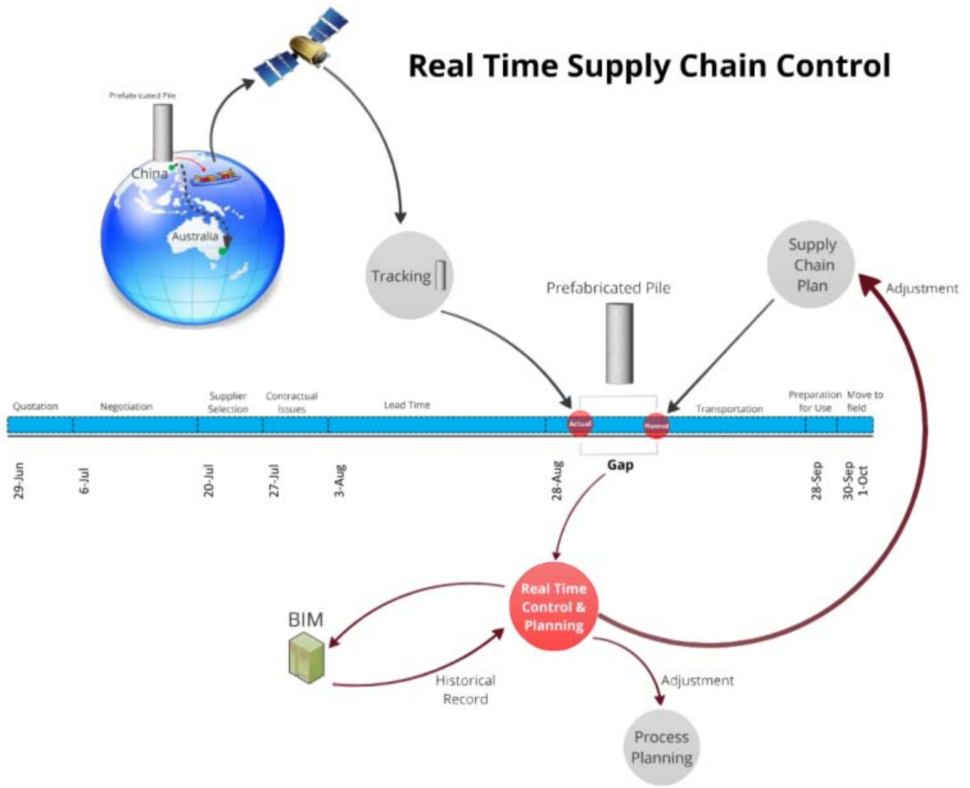

Figure 8:The controlling process for the piles

6. CONCLUSION:

The unexpected delays caused by a lack of materials on construction sites are a big challenge for managers. In this paper the concept of feed-forward control was applied with BIM in order to establish a platform that will be able to control the supply chain process automatically. BIM was selected in this paper as a central database, so rather than material, cost and time properties that are already embedded in BIM model, the supply chain properties also added to the BIM. The supply chain properties consist of a set of periods of time in a supply chain processes that are defined relative to the commencement date of the task requiring the components. Then based upon this data and the starting dates, which are defined by time properties, the supply chain plan for each component can be calculated automatically. Finally, this case study has shown how the concept of integrating BIM with a supply chain can provide valuable information to managers in advanced, which can lead to alleviate the negative effects of a lack of materials for the whole construction process.

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AN ADAPTIVE ALGORITHM FOR PREDICTION OF CONSTRUCTION ACTIVITIES PERFORMANCE

Levente Mályusz
Budapest University of Technology and Economics, Budapest, Hungary, lmalyusz@ekt.bme.hu

Attila Pém
Budapest University of Technology and Economics, Budapest, Hungary, apem@ekt.bme.hu

Abstract

Mathematical learning curve models can be used in construction to predict the time or cost required to perform a repetitive activity. In this paper we develop and evaluate an adaptive algorithm which gives sequential prediction for future performance of construction activities. Our evaluation was based on a survey conducted in the spring of 2009 in Budapest. Four mathematical models, Wright, DeJong, Stanford B moreover five data presentation methods, unit, cumulative average, moving average and exponential average are identified, and each are used in algorithm for prediction. Best fit for completed activities is cumulative average method and best fit for prediction of future performance is exponential average method. Among mathematical models DeJong model gave slightly better result than Stanford B and Wright models.

Keywords: algorithm, learning curves, construction time estimation.

1. INTRODUCTION

The aim of this paper is to contribute a development of algorithm for predicting construction activity time based on learning curve theory. The data for this study were collected by writers in a real reconstruction work of flat roofing insulation work. Learning curves imply that when numerous similar or nearly identical tasks are performed, the effort is reduced with each successive task (Fabrycky et al. [1], Oswald [2], Oglesby et al. [3], Drewin [4], Teplitz [5], Everett and Farghal [6,7], Lutz et al. [8], Lam et al. [9], Couto and Teixeira [10]). Learning curve theory can be applied to predicting the cost and time, generally in units of time, to complete repetitive activities. The cumulative average time method was used in the original formulation of the learning curve method, referred to as Wright's model, in Wright's famous paper on the subject [11]. A number of researchers have suggested that Wright's model is the best model available for describing the future performance of repetitive work (Everett and Farghal [6], Couto and Teixeira [9]). In (Malyusz and Pém [12]) the exponential average method with α =0.5 yielded the most accurate predictions. There is little information in the literature about uses of learning curves for construction activities, although it seems that the learning curve principle can be applied to repetitive construction operations (Hinze and Olbina [13]). In this study, we evaluated Wright model, DeJong model and Stanford B model for prediction of future data. Moreover we investigated data presentation models based on (Farghal and Everett [7] and Mályusz and Pém [14]).

2. THEORETICAL AND PRACTICAL BACKGROUND

2.1 Mathematical models

Learning curve theory is applicable to the prediction of the cost or time of future work, assuming repetitive work cycles with the same or similar working conditions in terms of technology, weather, and workers, without delay between two consecutive activities. The direct labor required to produce the (x + 1)st unit is assumed to always be less than the direct labor required for the xth unit. The reduction in time is a monotonically decreasing function, an exponential curve, as described in Wright's [11] paper.

In this study, we calculate the labor hours/square meter for each repeated activity.

Wright's linear log x, log y model is as follows:

$$lny = lna + blnx; \vee\, y = ax^b = ax^{log_2 r} \quad (1),$$

where ***x*** is the cycle number, ***y*** is the time required to complete cycle *x* in labor hours/square meter, **a** is the time required to complete the first cycle, ***b*** is a learning coefficient, and r is the rate of learning. For example if r=0.9 (90%), then b=–0.151. Wright discovered that when the labor cost decreases at a constant rate, that is, the learning rate, the production/cycles doubles. So learning rate is the constant rate with which labor time/cost decreases when the production/cycles doubles in a linear log x, log y model. This feature of the learning rate comes from the logarithms nature and true only in linear log x, log y model. We do not define the rate of learning in the other models.

Dejong model is a generalization of Wright's model based on the assumption that there is a minimum required time to complete a cycle. It is expressed with a so-called factor of incompressibility M.

$$y = a\left(M + \frac{1-M}{x^b}\right) = a_0 + (a - a_0)x^{-b}$$

M is between 0 and 1 where M = 0 represents a complete manual operation, and M = 1 describes a completely automatic operation. (Gottlieb and Haugbølle [15])

Stanford B model is another generalization of Wright's linear-log model based on the assumption that workers have experience. The experience is expressed with a so-called B-factor:

$$y = a(x + B)^b, lny = lna + bln(x + B)$$

Where B expresses the number of units produced before the first unit. The value of B will be in the range of 0–10 (Gottlieb and Haugbølle [15]; Kara and Kayis, 2005: 209).

S curve model consists of both the incompressibility M and the effect of experience factor B.

$$y = a_0 + (a - a_0)(x + B)^{-b}$$

Figure 1. shows the mathematical concept of the models.

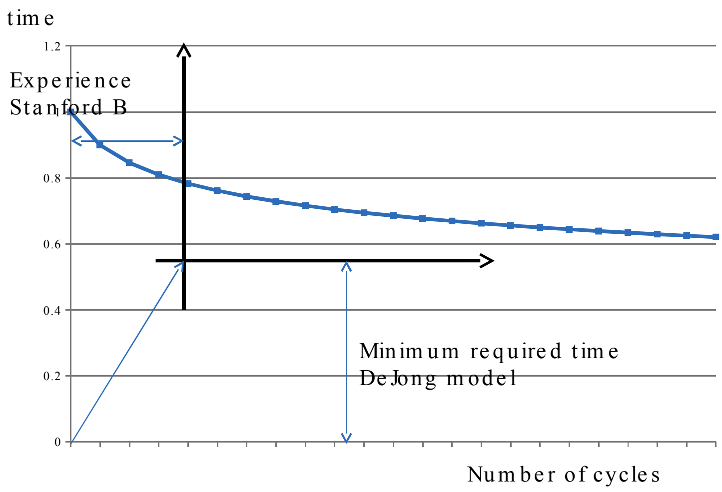

Figure 1: Stanford B and Dejong models

2.2. Data presentation

The unit is the data item that represents the time required to perform one cycle of the insulation work.

Wright (1936) discovered that the cumulative average **(CA)** time decreased by a fixed percent when the output doubles. CA represents the average time or cost of different quantities (x) of units.

$$CA_t = \frac{(Y_1 + Y_2 + \ldots Y_{t-1} + \ldots + Y_t)}{t}. \qquad (2)$$

where t is the number of cycles, CA_t is the cumulative average in cycle *t*, and Y_t is the unit time or cost for cycle *t.*

The moving average **(MA)** in this paper is the average time of the last 3 cycles. Although the MA is an average like the CA, the MA represents the most recent data. More points will help smooth the curve.

$$MA_t = \frac{(Y_t+Y_{t-1}+Y_{t-2})}{3}. \tag{3}$$

The weighted moving average (**WMA**) is a generalization of MA.

$$WMA_t = \frac{(tY_t+(t-1)Y_{t-1}+(t-2)Y_{t-2}+\ldots+Y_1)}{(t+(t-1)+(t-2)+\ldots+2+1)}$$

A weighted moving average has multiplying factors to give different weights to data at different positions.

The exponential average **(EA)** is a weighted average of the most recent data and the previous average.

$$EA_t = \alpha Y_t + (1-\alpha)EA_{t-1} \,.$$

$$EA_{t-1} = \alpha Y_{t-1} + (1-\alpha)EA_{t-2} \,.$$

$$EA_{t-2} = \alpha Y_{t-2} + (1-\alpha)EA_{t-3}.$$

That is,

$$EA_t = \alpha Y_t + \alpha(1-\alpha)Y_{t-1} + \alpha(1-\alpha)^2 Y_{t-2} + (1-\alpha)^3 EA_{t-3} \qquad (4).$$

where $\mathbf{EA_t}$ is the exponential average time for cycle *t*, EA_{t-1} is the exponential average time for cycle t–1, $\boldsymbol{Y_t}$ is the unit data (time to perform an activity) in cycle *t*, and $\boldsymbol{\alpha}$ is a coefficient. If $\boldsymbol{\alpha}$ is greater than 0.5, then the effect of new data is greater than that of older data. In this study, value of $\boldsymbol{\alpha}$, 0.5, was examined, based on Farghal and Everett [7].

Our assumption is that an exponential relationship exists between Y_t and *x*, i.e., between the time required to complete the activity for a given cycle and the cycle number. In other words, our assumption is that equation (1) holds. The relationship between log *y* and log *x* described by equation (1) can be plotted as a straight line on log–log paper, and all the regression formula apply to this equation just as they do to the equation. Mathematically, when x and y are given it is solvable for parameters *a* and *b* using the least squares method.

2.3. Description of the project

The data for this study were collected by writers in a real roof insulation work. The surveyed project was a reconstruction of flat roofing. During the reconstruction process, the circumstances and the weather were ideal for roofing (sunny, 26–33°C, no wind). The same workers performed the entire project. The technology was repetitive within one part. The workers knew that they were being monitored, but they were not informed as to what was being measured, and they were not disturbed. In the part of the reconstruction process that was studied, the work under consideration consisted of the following activities: slicing up the old waterproofing, laying down 10-cm-thick heating insulation and attaching it to the roof using screws, spreading one layer of rubber waterproofing, and melting it to the cape of the screws. The joining, the fixing of the edges, and the changing of the roof windows were not surveyed. The timer was stopped whenever the workers took a break or performed any activity that was not being studied. Time to complete one cycle was measured only. The workers were not disturbed. The timer was stopped when workers took a break.

The roof of the hall building was divided into 7 sections. The activities were repeated in one section after another, as shown in Figure 1. The areas of the sections were not all the same, so during the evaluation, we calculated the labor hours/square meter.

During the work on the 5^{th} section, a storm caused some damage to the completed sections that the workers had to repair. These two days were not measured, but the storm did negatively affect the workers' progress.

3. LEARNING ANALYSIS OF HALL BUILDING

3.1. Input data

In Table 1, the input raw data for the hall building are in the "Unit" Column. The units of the numbers in the Unit, CA, MA, WMA, and EA(0.5) columns are labor hours/square meter.

Cycle x	Unit	CA	MA	WMA	EA(0.5)
1	2.132	2.132	2.132	2.132	2.132
2	1.789	1.961	1.961	1.903	1.961
3	1.588	1.836	1.836	1.746	1.775
4	1.54	1.762	1.639	1.663	1.658
5	1.575	1.725	1.568	1.634	1.617
6	1.546	1.608	1.554	1.609	1.582
7	1.541	1.558	1.554	1.592	1.562

Table 1: Raw input data of hall building (in labor hours/square meter)

3.2. Algorithm

After the first three cycles the linear relationships between ln(x) and ln(Unit), ln(x) and ln(CA), ln(x) and ln(MA), ln(x) and ln(WMA), and ln(x) and ln(EA(0.5)) were calculated based on the principle of least squares using Libreoffice Calc 4's built-in function "linest." Results of this calculation are parameters a and b in equation (1). We have 5 different functions and parameters because we fit regression lines to unit data, CA, Ma, WMA and EA. With a help of this parameters we can predict the 4^{th} values of unit data, CA, MA, WMA and EA. Now we have 5 predictions for time required to complete cycle 4. How can we choose among 5 predictions? We chose that one which came from “the best data presentation method for historical data” estimation. Result of this algorithm for Wright's model (for B=0, a_0=0) are summarized in Table 2 and Table 3. For example in Table 2, after the first 3 cycles the best data presentation method is Unit method, because it has the best accuracy (0.02). The accuracy of predicted value of Unit method for the 4th cycle is in Table 3, that is 0.06. After the first 4 cycles the best data presentation method is WMA, because it has the best accuracy (0.05). The accuracy of predicted value of WMA for the 5th cycle is in Table 3, that is 0.11. After completing a cycle we estimate the time required to complete next cycle. In Table 3 column “Algorithm” gives the estimated values for next cycles. Considering Table 3, 5, 7, although our algorithm did not give the best result but it gave an acceptable estimation for completion time of next cycle.

Cycle x B=0, a_0=0	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	**Best Fit**
3	0.02	0.05	0.19	0.05	0.16	UNIT
4	0.08	0.07	0.49	0.05	0.22	WMA
5	0.25	0.12	0.58	0.15	0.22	CA
6	0.36	0.18	0.61	0.25	0.25	CA
SUM	0.7	**0.42**	1.86	0.49	0.85	

Table 2: Accuracies of least curve regressions for the first x data

Based on Table 2 the best data presentation method for historical data is CA in Wright model.

Cycle x B=0, a_0=0	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0,5**	**Algorithm**
4	0.06	0.05	0.41	0.01	0.12	0.06
5	0.14	0.06	0.19	0.11	0	0.11
6	0.1	0.11	0.02	0.15	0.03	0.11
7	0.1	0.16	0.15	0.2	0.07	0.16
SUM	0.41	0.39	0.77	0.46	**0.22**	0.44

Table 3: Accuracies of predictions based on the first (x–1) data

Based on Table 3 the best data presentation method for prediction is EA(0.5) in Wright model.

Cycle x B=5, a_0=0	UNIT	CA	MA	WMA	EA; 0.5	Best Fit
3	0.04	0.02	0.19	0.03	0.08	CA
4	0.2	0.12	0.39	0.14	0.08	EA
5	0.4	0.32	0.4	0.34	0.2	EA
6	0.52	0.51	0.62	0.53	0.3	EA
SUM	1.17	0.98	1.59	1.03	**0.65**	

Table 4: Accuracies of least curve regressions for the first x data

Based on Table 2 the best data presentation method for historical data with Stanford B model is EA(0.5).

Cycle x B=5, a_0=0	UNIT	CA	MA	WMA	EA; 0.5	Algorithm
4	0.14	0.15	0.26	0.15	0	0.15
5	0.21	0.31	0.02	0.29	0.13	0.13
6	0.15	0.39	0.24	0.34	0.16	0.16
7	0.14	0.46	0.35	0.38	0.18	0.18
SUM	0.64	1.31	0.86	1.16	**0.47**	0.61

Table 5: Accuracies of predictions based on the first (x–1) data

Based on Table 5 the best data presentation method for prediction with Stanford B model is EA(0.5). Next Tables show results with DeJong model, where B=0 and a_0=1 that is, in our example 1 hour is the minimum required time to complete 1 m^2.

Cycle x B=0, a_0=1	UNIT	CA	MA	WMA	EA; 0.5	Best Fit
3	0.05	0.07	0.19	0.07	0.18	UNIT
4	0.06	0.09	0.52	0.08	0.28	UNIT
5	0.2	0.1	0.62	0.13	0.3	CA
6	0.29	0.14	0.63	0.18	0.31	CA
SUM	0.6	0.39	1.96	**0.46**	1.07	

Table 6: Accuracies of least curve regressions for the first x data

Based on Table 6 the best data presentation method for completed activities with DeJong model is CA.

Cycle x B=0, a_0=1	**UNIT**	**CA**	**MA**	**WMA**	**EA; 0.5**	**Algorithm**
4	0.03	0.08	0.43	0.04	0.14	0.03
5	0.11	0.01	0.22	0.06	0.02	0.06
6	0.08	0.05	0.02	0.09	0	0.05
7	0.07	0.08	0.1	0.13	0.03	0.08
SUM	0.29	0.22	0.76	0.32	**0.19**	0.22

Table 7: Accuracies of predictions based on the first (x–1) data

Based on Table 7 the best data presentation method for prediction with DeJong model is EA(0.5).

4. RESULTS AND CONCLUSIONS

In this paper we develop and evaluate an algorithm which gives sequential prediction for future performance of construction activities. Four mathematical models, Wright, DeJong, Stanford B moreover five data presentation methods, unit, cumulative average, moving average, weighted moving average and exponential average are identified, and each are used in algorithm for prediction. Best fit for completed activities is cumulative average method and best fit for prediction of future performance is exponential average method. Among mathematical models DeJong model gave slightly better result than Stanford B and Wright models.

	best fit for completed activities	best predictors of future performance
Everett and Farghal [6],	cubic model	Wright model
verett and Farghal [7],	unit data representations	unit data representations
Thomas et al. [17]	cubic model	–
Kara and Kayis [18]		Wright model
Malyusz and Pem [12]	linear log x, y with cumulative average	linear x log y model with cumulative average;
In this paper	Cumulative average	Exponential average

Table 8: Comparing our results with others in literature

Table 8 shows a comparison of different results from literature. Unfortunately it is very difficult to compare the different results because not only the investigated data but the set of analyzed models were different in each paper. Further investigation is necessary with more data and with more sophisticated mathematical and learning curve models.

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A DESIGN ARTIFACT FOR FUNCTIONAL ASSESSMENT OF CONSTRUCTION PROJECTS

Cyril Mauger
Public Research Center Henri Tudor, Luxembourg, Luxembourg, Laboratoire Conception Fabrication Commande, Arts et Métiers ParisTech, Metz, France, cyril.mauger@tudor.lu

Abstract

In architectural design process, architects' drawings provide spatial visualization of the project answering the client's requirements gathered in the brief. Their assessment is usually performed manually by following a set of evaluation criteria defined by the client. Functional assessment is based on activities textually described in the brief and graphically synthesized in functional diagrams. As it is performed manually and considering the large amount of requirements contained in a brief, only a limited set of requirements could be checked and the overall coherence of the analysis often remains difficult. This paper proposes a design artifact, called the meta-space diagram, aiming at supporting this functional assessment. This design artifact is based on a literature review on functional modeling in Engineering as well as on space layout techniques used in Architecture (e.g. graph, bubble diagram). A retrospective analysis of an existing building, its brief and subsequent plans, serves as a basis to develop and to first evaluate the proposed design artifact. The meta-space diagram is an enhanced oriented and labeled graph. It can model two kinds of artifacts in the same form: activities and processes described by the client in the brief, and architects' space proposals. As the building should support the service it is supposed to provide, both meta-space diagrams have to match. Alignment between the two models is ensured by spatial allocation and grouping based on the client's requirements. The meta-space diagram tackles issues related to loss of information/requirements and imprecision between the brief and the proposals. It provides elements to be discussed by the client and the architect to make evolve both the brief and/or the design toward compliance with what the client really wants. It constitutes a first step toward automation of the functional assessment. The next step is its application on a larger case study to confirm the first presented results.

Keywords: architectural programming, functional analysis, project assessment, space layout, visualization technique.

1. INTRODUCTION

Architectural design competitions contribute to the stimulation of creativity in the design process of architects. As a result, for one and the same brief, an interesting variety of projects is generated (RIBA, 2013). Even though architectural design competitions exist for a very long time (Jong and Mattie, 1995), their regulation remains recent and became more and more important in these last years to promote fairness (AIA, 1988; ISO, 1994). In France, since 1985 (JORF, 2007), architectural competitions are even a legal prerequisite for public construction projects exceeding a certain budget (Cabanieu, 1994). Among the variety of projects submitted, only one will be chosen by the contracting owner through a selection process. This selection process follows a set of criteria defined in advance by the contracting owner in the competition conditions. They are derived from the brief and usually a small set of them concerns the overall functionality. This functional assessment is based on activities, use cases and scenarios textually described in the brief and graphically synthesized in functional diagrams. It concerns operational requirements defined by the users answering the How question of the brief (Bisbrouck, 2004).

In France, this assessment is usually performed by a Technical Committee composed of experts and users. It is performed manually following a predefined set of criteria. Despite the large amount of requirements contained in a brief, only a limited set of requirements and viewpoints can be checked. As a result, the overall coherence of the analysis often remains incomplete, difficult and lengthy. Even if objectivity is a pillar of this assessment, the process remains individual and inclined toward subjectivity (Bisbrouck, 2006).

This paper focuses on the question of how to support the functional assessment of architects' proposals based on requirements contained in the functional diagram. The proposed answer is a design artifact called the meta-space diagram, an enhanced oriented and labeled graph. The contribution of this paper concerns its use to fill the gap between the concept of operational requirements and space (e.g. the process). The meta-space represents a first artifact to prepare an automation of the functional assessment. Then, the difficult task of upstream integration of requirements from the brief with BIM and CAD tools for design support could be considered. The research issue is based on the postulate that the functional diagram synthesizes a minimal set of operational requirements, which is a necessary but non-sufficient condition. These operational requirements are supposed to be rationalized in the brief and should be checked during the functional assessment. Both, this postulate and the design artifact are introduced and further developed in a previous paper regarding the processing of requirements (Mauger and Kubicki, 2013).

The design artifact is based on a literature review on functional modeling in Engineering as well as on space layout techniques used in Architecture (e.g. graph, bubble diagram). A retrospective analysis of an existing building, of its brief and subsequent plans, serves as a basis to develop and to first evaluate the proposition.

The second section of this paper presents a short review of functional modeling and assessment in Engineering and their context in Architecture. The third section summarizes the principle of the meta-space diagram as an artifact for design, analysis, and evaluation. The fourth section describes the retrospective application of this design artifact on a design competition for a multimedia library in Brittany. The last section of this paper ends with discussions and conclusions about the use of meta-space diagrams for the functional assessment of architects' proposals.

2. FUNCTIONAL MODELING & ASSESSMENT

Functional modeling corresponds to the activity of modeling systems based on their functionalities. It focuses on representing knowledge about function (Erden et al., 2008). The graphical framework plays an important part in order to benefit from shared understanding and automation. Its main use concerns the design phase of system development. Each systematic design approach or method proposes its own definition and representation of the concept of function or functionality in a more or less operational way (Ross and Schoman, 1977; Gero, 1990; Pahl and Beitz, 1995; Umeda and Tomiyama, 1997; Suh, 1998). In Engineering, as a general understanding, a function is defined as what a system does, i.e. an action performed by a product (system) or its components. Functions are defined on the basis of the clients' demands of the object to design. Functional assessment of the designed object is realized by measuring its performance achievements through, inter-alia, prototypes or simulations.

In Architecture, two kinds of functions should be considered:

- The first one corresponds to the Engineering definition: what the building does (Gobin, 2006). Most of the current research on functional assessment relates to this definition of buildings' behavior. They refer to the technical services of a building (e.g. HVAC), more specifically to energy and environmental performances, i.e. sustainability (Kaatz et al., 2006; Ding, 2008). These works have their own model and assessment tools and methods (Roderick and McEwan, 2009).
- The second one refers to an Architecture definition: the human activities performed inside the building, i.e. its use. The "rationalism" and more specifically the "functionalism" movement in architecture gave an extreme echo to this concept at the beginning of the 20th century through famous architects such as Viollet-le-Duc (Viollet-le-Duc, 1863), Gropius and Meyer (Whitford, 2005), Mies van der Rohe and Sullivan (Lobos and Donath, 2010), or Le Corbusier (Le Corbusier, 1923).

This paper focuses on the second definition of function, i.e. performance of human activities. In the briefing process, functional diagrams are used to model the human activities, i.e. operational requirements (Bisbrouck, 2004). It graphically synthesizes the organizational and functional dependencies between the functional spaces based on the description of the human activities contained in the brief. A space planning resumes its essential content into "numbers and words" (Lobos and Donath, 2010). The functional diagram represents the dynamic part of human activities whereas space planning resumes its static part. The assessment of the building use is part of the selection process. Based on this information, the Technical Committee has to check if the architects' proposals satisfy the future use and to highlight potential issues (Bisbrouck, 2006). In France, this Technical Committee is not legally mandatory but highly supported due to its proved necessity (JORF, 1993; MIQCP, 2012).

Despite its importance, the functional assessment regarding the use of buildings is not prevalent in the selection process. The functional assessment performed by the Technical Committee cannot anticipate the jury's conclusion of the selection process(MIQCP, 2012). It remains an objective, factual assessment contrasting with the selection process. As a result, quite often, the key criterion of selection remains an aesthetic or poetic aspect of proposals despite the "user" or the Technical Committee's opinion (Bisbrouck, 2006). The composition of the jury seems to partly explain this by the prevalence of architects (at least a third of the jury in France (JORF, 1993)) compared to user representatives (usually one or two persons).

3. META-SPACE DIAGRAM

3.1. Design Artifact Principle

The meta-space diagram is defined as an abstraction of the functional diagram. Its first use is to process requirements and design the functional diagram during the briefing process. The functional diagram synthesizes organizational and functional requirements further developed in the brief. The meta-space diagram is developed to keep a trace of these requirements from the brief to the functional diagram. Figure 1 outlines the principle of meta-spaces based on activities, required resources, process and operational requirements taken from the book cycle in a library, i.e. the processing of new incoming documents. A meta-space is considered as an ideal virtual space gathering all the necessary requirements for activity performance. It represents an abstraction of the concept of activity, making it easier to analyze and manipulate through automation.

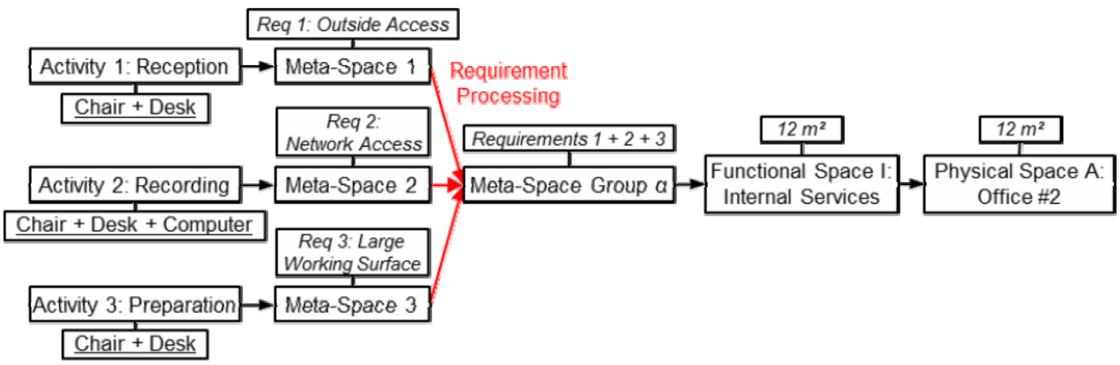

Figure 1: Meta-Space principle illustrated on the book cycle

A meta-space diagram is an enhanced graph relative to the Graph Theory (Euler, 1736; Grason, 1971) and bubble diagrams (Séquin and Kalay, 1998) but used in a different context and purpose. The layout was not the focus of this design artifact but could later benefit from or to it. The meta-space diagram synthesizes the grouping based on requirements into a graph but keeps trace of the activities (Figure 2) through an associated data-base. The information model of the data-base is under development and will be presented in another paper. The grouping principle is the same as in affinity diagrams (Alread and Leslie, 2006) or zoning diagrams (White, 1986) but extended with successive activities and dynamic behaviors related to flows of artifacts or human activities.

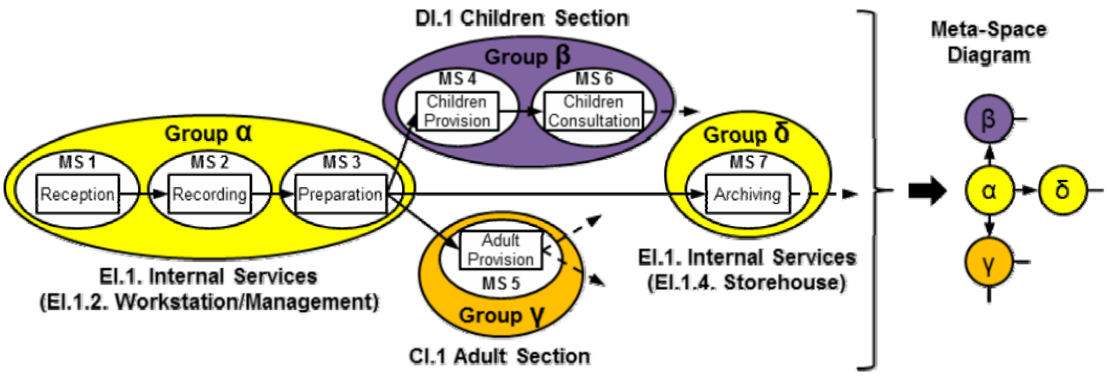

Figure 2: Meta-Space Diagram Principle illustrated on a limited part of the book cycle

3.2. Analysis Artifact Principle

In this paper, the meta-space diagram is used as an analysis artifact. Based on the plan, physical spaces instantiated by the architect in his proposal are identified. Associated functionalities are deduced from an analysis of the architect proposal. Usually, the architects provide this information in their proposal to ease the reading of their plan. Thereafter, functional spaces are turned into meta-spaces. Entrances are derived first into links between functional spaces then into links between meta-spaces. Each arrow in the left part of Figure 3 represents a change of abstraction level from concrete (project plan) to abstract (meta-space). The meta-space diagram graphically synthesizes the project plan in an abstract way, linking meta-spaces to each other using links.

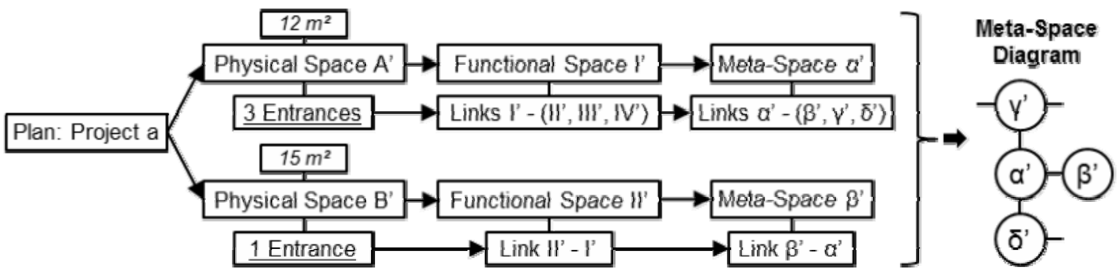

Figure 3: Meta-space diagram creation based on a project plan

3.3. Evaluation Artifact Principle

A functional diagram and architect's plan are two very different graphical models, using a distinct syntax. Their direct comparison is impossible. Moreover, their layout can be totally different. Sub-section 3.1 and 3.2 presents how the functional diagram and the plan of the architects' proposal can be modeled into meta-space diagram. As a result, both are represented on the same level of abstraction with the same syntax and can then be compared. The evaluation consists in comparing the functional diagram meta-space diagram to the project plan meta-space diagram and thus to identify the differences. The functional diagram meta-space diagram is supported by a data-base containing the operational requirements related to each meta-space and link. Thus, missing links or meta-spaces lead to potential issues in the use of the building. These issues can be properly identified upstream then specific modifications can be suggested to architects. This would participate to ensure functional quality of the detailed design after winner selection.

4. APPLICATION & PROCESS

In order to illustrate and validate the propositions of section 3, the design artifact is retrospectively applied in the architectural design competition for a multimedia library in Brittany. Input information was extracted from the competition documents provided by the contracting owner: the brief, the competition conditions, the three project proposals documentation, the technical review, and the official selection report. The meta-space diagram of the functional diagram was first drawn based on the brief and complementary resources on libraries. Each proposal was then analyzed, reproduced and turned into meta-space diagrams. Each proposal meta-space diagram was compared to the original meta-space diagram to identify deltas.

4.1. Functional Diagram

The principle and design of the functional diagram based on meta-spaces (Mauger and Kubicki, 2013) is not the focus of this paper, but its use is. The global synthesis of the functional diagram is presented in Figure 4. In order to facilitate understanding and shorten the analysis, only the general relations between functional spaces are represented. For the same reasons, the distinction between public and personal flows is not taken into consideration in this paper.

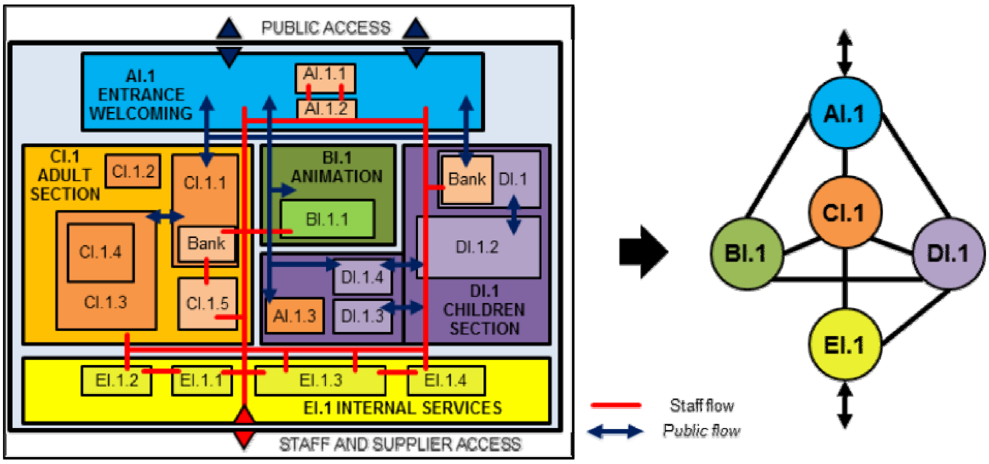

Figure 4: From functional diagram to meta-space diagram

4.2. Architects' Proposals Analysis

Project B was developed to illustrate the analysis of the architect's proposals. The architect's proposal was reproduced on an approximate scale but respecting the general layout and accesses (Figure 5). Following the process described in section 3.2 and in Figure 3, the main functional spaces were identified and transformed into meta-spaces. Accesses were transcribed into links connecting the different main functional spaces. Stairs are represented by dash lines and the goods elevator by a dash dot line. Multiple accesses from and to the same functional space are indicated by a single line. Entrances from outside are drawn as double arrows lines. Project A and C were also analyzed and drawn in the same way. Meta-spaces composing the diagram were moved to have the same layout as the functional diagram in order to facilitate their assessment. As a matter of fact, the layout of the bubble has no importance for the functional assessment, whereas connections between meta-spaces have.

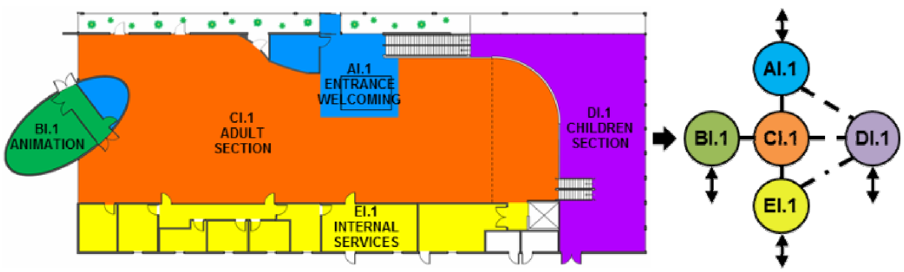

Figure 5: Analysis of project B

4.3. Architects' Proposal Assessment

Figure 6 represents the functional diagram and the three architects' proposal using meta-space diagrams. The four design artifacts can therefore be compared on the basis of using the same graphical syntax. This assessment was done to prepare the interview with the library director. By doing it this way, a validation of this assessment regarding the selected, built and used project was possible. The result of this high level assessment is resumed in four points:

- Overall: missing link between Animation and Children Section, required to cross either the Adult Section or the Entrance, addition of emergency exits
- Project A: closely matches the functional diagram, with the exception of the missing direct access from Adult Section to Children Section
- Project B: missing link between Entrance and Animation, two layers, basement dedicated to the Children Section, an access to the Animation from the outside is claimed
- Project C: Entrance as single distribution space, centralized design, two layers, basement dedicated to Internal Services

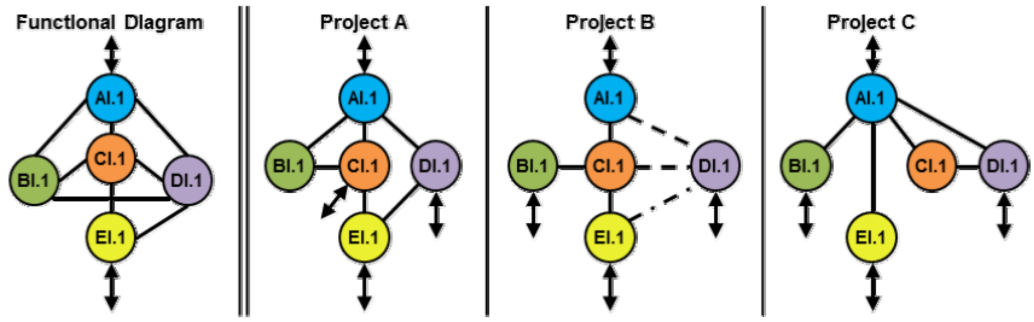

Figure 6: Proposals assessment regarding the functional diagram

Based on the postulate that each link and functional space in the functional diagram is a necessary condition, the assessment does not need to focus on what matches, but only on deltas. Then deltas are analyzed with regard to the functional diagram information or information given by the architects. For example, for project B and C, the book cycle is complicated by the elevation in project B and the mandatory passage through the entrance/welcoming in project C. The book cycle requires functional services to be easily accessible from both adult and children section. The elevation in project B regarding the children section will lead to difficulties in terms of human resources, as children cannot be on their own. It requires having one extra person to deal with it.

4.4. Feedback

The Technical Committee Report does not provide so many details about the functional assessment of proposals. All of them were evaluated as satisfying. Project A was perfectly fine, without any negative comments. The elevation in Project B raised open questions in terms of use, noise and elevator, but without so many details. The pronounced separation of the Internal Services in Project C also raised open questions about its use and the surveillance of the other sections. Even if this functional assessment is not predominant in the selection process, it will be necessary to deepen the functional analysis later in order to ensure that all the services and uses can be properly performed and that acceptable solutions or changes will be proposed. At the end of the selection process, Project B was chosen, regardless of the functional issue raised by the Technical Committee.

After the analysis of the technical report, an unstructured interview with the library director was held to confirm or deny observations made on Project B. The functional issue rose by both the meta-space diagram analysis and the Technical Committee was confirmed. No solutions were found regarding this during the design process. Each time when human resource needs were scheduled, an extra person had to be added to deal with the Children Section.

5. CONCLUSIONS AND PERSPECTIVES

The meta-space diagram is a design artifact developed to support the briefing process. Based on information gathered in the model, the functional diagram is designed for keeping trace of the rationales. This paper introduces its use for the functional assessment of architects' proposals using these rationales and the same graphical model. Its application on a retrospective case study shows that missing operational requirements could be found in the architects' proposals. Details of these operational requirements were lost in the current practices partly due to the lack of support. Keeping trace of these operational requirements is very difficult, considering the amount of information contained in the brief. As a result, issues lightly raised during the functional assessment persist in the use of the building. In the developed case study, this led to extra costs for human resources. These extra costs are permanent, or solving the issue will require a considerable effort. The meta-space diagram is a way to highlight these functional issues providing sufficient details and accuracy.

However, the presented results are limited to a global analysis of the proposals. Few details are provided to receive effective benefits from the design artifact. A larger and deeper application in a real case study, from brief to selection process, would give a better idea of its added value. This paper gives a possible, but limited insight into the application of meta-space diagrams to functional assessment. One of the most important aspects that make it interesting is the information model attached to the meta-space diagram. It provides all the rationales in the analysis of proposals. The next step of this research will be to develop and implement such an information model. The link to the existing requirements model specification (Kiviniemi, 2005) and the IFC specification is part of the perspectives. Thereafter, automation of delta detection could be considered.

The functionality of a proposal seems to be considered as an acceptable issue which can be solved in the design process. Reality demonstrates two things that have not been developed in this work. First, the realignment of a proposal requires a lot of effort, in time and means, by both the client and the architect. Second, the realignment can only be partial due to the lack of support in the modeling and assessment of functionality. As functionality cannot be a discriminant criterion, this paper poses an open question: how can one ensure the functional quality of all proposals at the earliest possible stage? Therefore, if all proposals are equally functional, only the creativity of architects will be assessed without fear for the building use by its future users. This open question is partially tackled here by proposing a design artifact, the meta-space model, initially developed for the briefing process, but introduced as an analysis support for functional assessment in this paper. This design artifact could later on be adapted to support the design process of buildings by integrating it to BIM or to a CAD tool. In order to allow this extension, operability issues between the information model, the design artifact and existing BIM approaches and CAD tools will have to be considered.

ACKNOWLEDGEMENTS

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METHODOLOGY FOR OPTIMIZATION MODAL PARAMETERS IN THE ENGINEERING DESIGN PROCESS ON THE EXAMPLE OF CONTINUOUS MINER CUTTER BOOM

Arkadiusz Mężyk
Silesian University of Technology, Gliwice, Poland, arkadiusz.mezyk@polsl.pl

Mariusz Pawlak
Silesian University of Technology, Gliwice, Poland, wojciech.klein@polsl.pl

Wojciech Klein
Silesian University of Technology, Gliwice, Poland, wojciech.klein@polsl.pl

Jan Kania
Silesian University of Technology, Gliwice , Poland, jan.kania@polsl.pl

Abstract

Continuous miners are the basic excavating machines in many mines. Their structures are exposed to a complex interaction of the dynamic forces that cause vibrations and shocks. This can lead to the excessive wear of individual components and/or catastrophic breakage. The paper shows the methodology for the modal parameters optimization of the cutting boom. Geometrical model of cutting boom was designed in CAD software, but in order to have a consistent parametric model for the optimization of all data, it was rewritten in LS-PrePost command file. An objective function was applied and designed for maximization of differences between eigenfrequencies and excitation peak force frequencies with respect to the total mass of the boom. Genetic algorithms' optimization method was used for searching the best combination of specified parameters. The influence of parameters on mass and frequencies is presented in a sensitivity analysis. During the optimization process, geometrical reshape model was applied in order to change specified design variables. The results of the modal analysis are part of a complex dynamic simulation of the cutter boom which integrates transmission, drives and cut header interacting.

Keywords: optimization, numerical modal analysis, continuous miner, genetic algorithms

1. INTRODUCTION

Rock cutting process requires the use of specialized equipment, especially the one which is extremely shock and vibration resistant. Thus, the design process should take into consideration the influence of excitation forces and moments. Figure 1 presents both the resultant torque of loads during normal interactions between cutting head and long wall and its FFT signal.

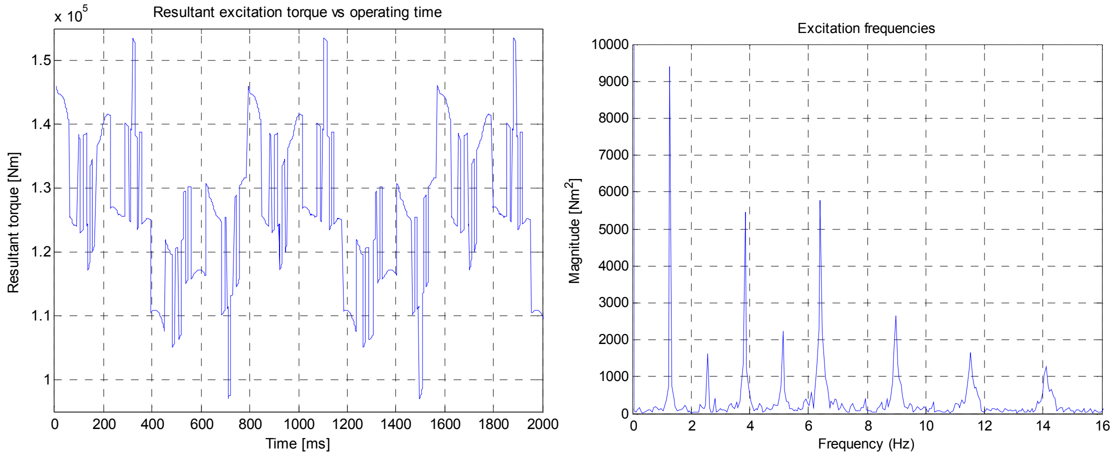


Figure 1: Signal of resultant excitation torque vs. operation time and FFT analysis

The most important assumption of design process, is that overlapping of excitation frequencies and eigenfrequencies of the analyzed system, should be avoided. This causes increase of vibration and shock as a consequence of resonance phenomena. To avoid this effect and improve the dynamic characteristic of highly complex systems, such as continuous miner boom (figure 2), there is a possibility of modification of some geometrical parameters without affecting functionality and strength. On the other hand there is a possibility of applying different types of the passive, semi-active and active vibration control systems. However, this solution is usually expensive and has significant influence on complexity of the whole structure.

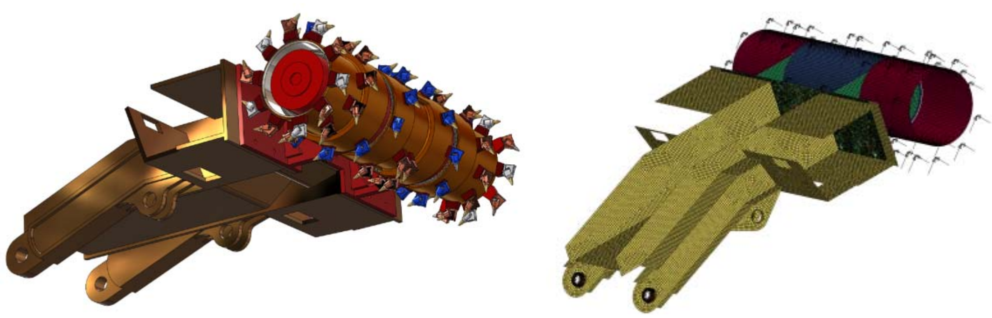


Figure 2: The CAD and FEM model of continuous miners boom

2. OPTIMIZATION PROBLEM

The optimization problem is focused on finding values of parameters for which eigenvalues of structure are maximally spaced from excitation frequencies. This specified parameters have to be selected from geometrical feature and at the same time their values should highly influence on stiffness and mass matrix of finite element model respect to following equation:

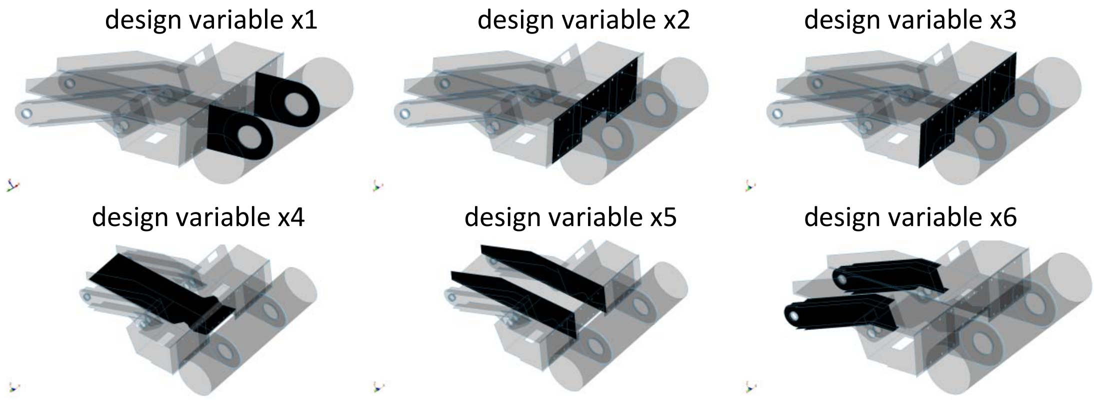
$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{M}} \quad (1)$$

where:

fn – natural frequency [Hz],
K – stiffens matrix,
M – mass matrix,

Changing of particular body wall thickness will affect the specific K stiffness matrix elements values and the change of M mass matrix. This will reflect on eigenvalues of structure depending on the type of design variables. Thus, the selection of the design variable should be verified using sensitivity analysis.

The design variables represent thickness of continues miner boom components and are shown on figure 3. They have definitely impact on total mass of boom and change eigenvalues of the fifth mode shape .



Fiure 3: The visualization of selected design variables

The proposed objective function take into account also minimization total mass of analyzed structure and is defined as:

$$OBJFUN_k(X_i) = abs\left(VFEP_n + \left(\frac{VFEP_{n+1} - VFEP_n}{2}\right) - EV_k\right) + \frac{W1*MASS}{VFEP_{n+1} - VFEP_n} \rightarrow min \quad (2)$$

While the generalized equation for multiply eigenvalues optimization can be write as:

$$OBJFUN(X_i) = \frac{\sum_{k=1}^{p} OBJFUN_k(X_i)}{p} \rightarrow min \quad (3)$$

where:

VFEP –value of frequency excitation peak,
EV – eigenvalue,
X – design variable,
MASS – total mass,
W1 – weight ratio,
i – specific design variables,
k –specific eigenvalue,
n – subsequent excitation peak in specific range,
p –number of eigenvalues taking into consideration.

Applied objective function has an explicit form, however, parameters responsible for EV/eigenvalues are of an implicit character and they result from the mathematical model of cutter boom written using FEM formalism.

Thanks to the application of generalized description it is possible to issue the problem of structure optimization in broader range of excitation frequency and increasing number of eigenvalues. However, in the aim of showing the applied methodology of action in this paper, simulation was limited to the vibration frequency of the fifth in the range of excitation frequency from 8 to 16 Hz.

3. SENSITIVITY ANALYSIS

At the beginning of analysis all shells had thickness 0.05 m, and sensitivity analysis was done by linear changing of one design variable and note response of model. The following graph shows sensitivity of total mass and fifth mode shape eigenvalue on particular design variables.

Assuming thickness of boom cutter arm x = 0.05 m ,modal analysis vibration frequency of a fifth was 9989 Hz. Equating to chart 1 it is shown that it is too close to one of the frequency of excitation resulting from the excavation of the material. In modal analysis, by changing only one parameter in the range of 0.01 to 0.1 ,a graph of vibration frequency sensitivity of the individual variables was produced. A characteristic change in frequency of the fifth mode shape variations in a function of the variable x is the following figure. Together with the change in the wall thickness there is also a change of the total weight of boom cutter arm, which is also shown in the figure below.

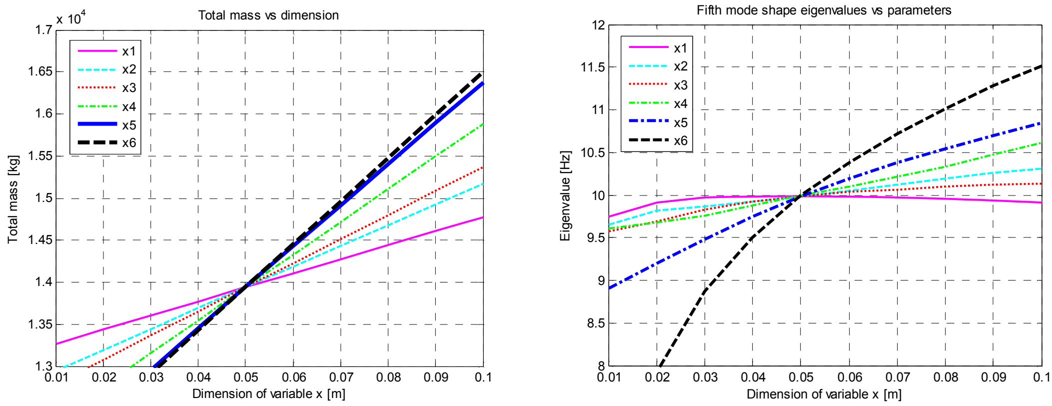


Figure 4: Sensitive of total mass and fifth mode shape eigenvalues for design variables

Variables x5 and x6 have the most important influence on the vibration frequency of the fifth, there is small influence of the variables x1 and x3. In case of the total weight of boom cutter arm, variables x5 and x6 have the biggest impact, the smallest have variables x1 and x2.

In our issue of optimization, where the aim is to reduce the total mass of the system and obtain the frequency of the variables within a certain range, finding a simple correlation is difficult. Figure 5 shows the changes of the vibration frequency of six for the individual variables.

The growing trend both in mass and eigenvalue indicates that these parameters have the strongest influence on geometrical stiffness matrix according to equation 1. The influence of particular objective variables for other mode shapes is presented on the following graphs.

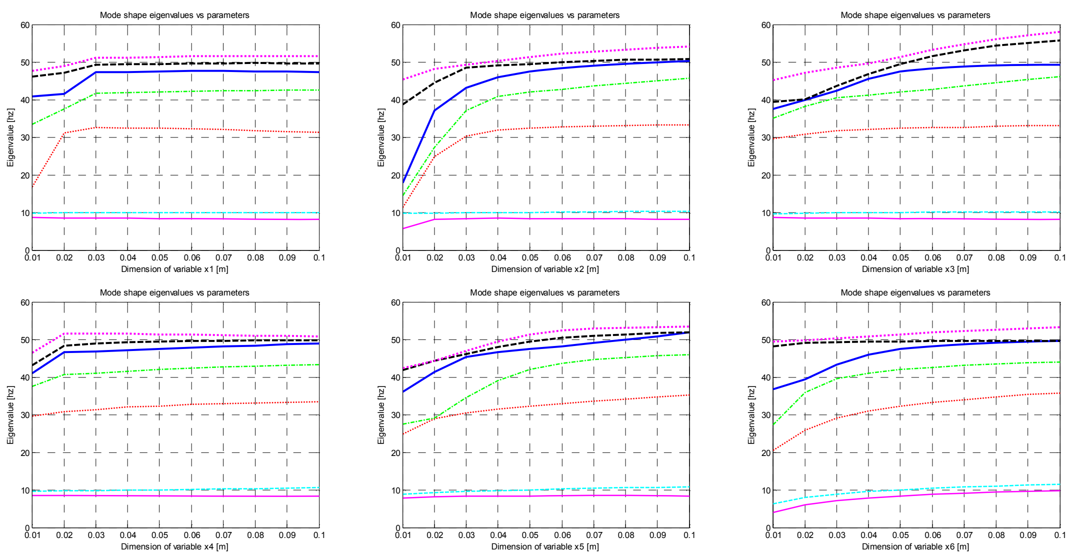


Figure 5: Mode shape eigenvalues vs. design variables (x1, x2,… x6)

4. OPTIMIZATION PROCES AND RESULTS

The optimization process was done by genetic algorithm which is implemented in MATLAB software. The connection between FEM environment and optimization method was made by both input file and output file.

Based on the sensitivity analysis, it is difficult to determine the size of the variable x, at which the system would have both the vibration frequency away from the frequency of extortion, and the minimum weight. It was therefore decided to carry out a process of multi-criteria optimization based on genetic algorithm. The main task of the optimization process is to define the objective function in such way that boom cutter arm vibration frequency was the most distant from the frequency of excitations of the cutting material. The module Matlab Optimization Toolbox was used to optimize. It managed the generation of the input file to LS PrePost software, as well as, running calculations in LS Dyna software and reading the results of a modal analysis of the output file. The complexity of the calculation results from the formation in the preprocessor LS PrePost a geometric parametric model of a boom cutter arm, where the discretization of the object, creating a mathematical model and file generation LS Dyna software happen.

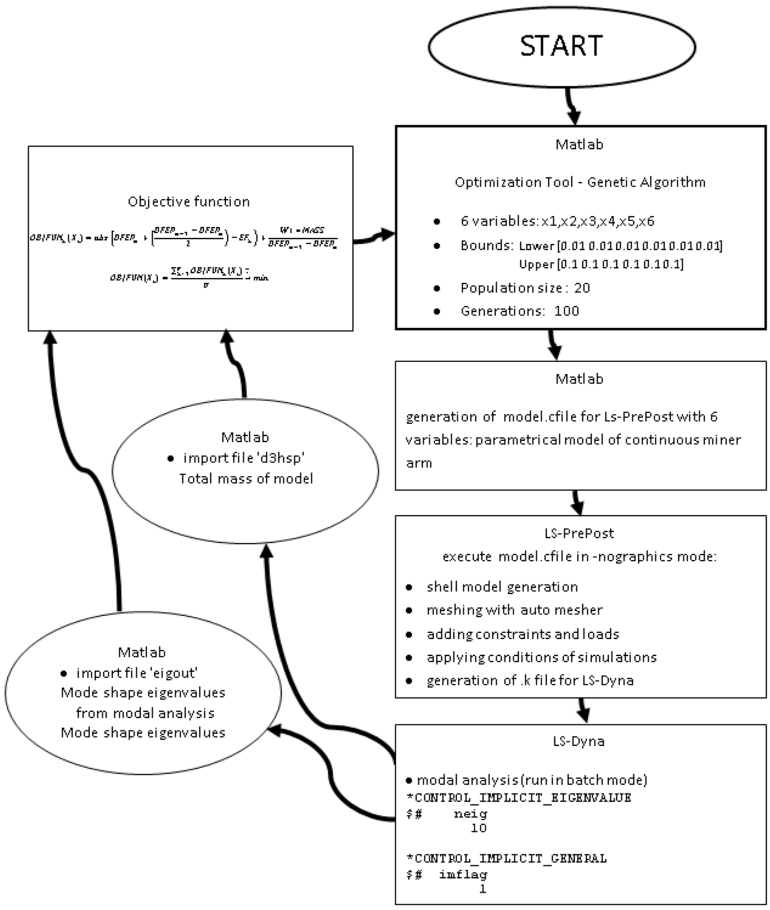


Figure 6: Methodology of applied optimization process

Model for modal analysis consists of 19 shell parts- 5762 nodes, 56714 shells from which 16674 are rigid elements and 40040 are deformable elements. The variables during optimization process could balance from 0.01 to 0.1 m.

The stopping criteria for genetic algorithms was set to 100 generations but the process stops at 52th generation, where an average change in fitness values was less tolerant than assumed. The optimization process took 12 hours and 1040 modal analysis files in LS-Dyna were executed.

The figure 7 presents 52 generation and the best, the average, and the worst values of the objective function. The algorithm during the operation found a local minimum and after mutation it improved the value of the objective function from about 0.0651 to 0.0645.

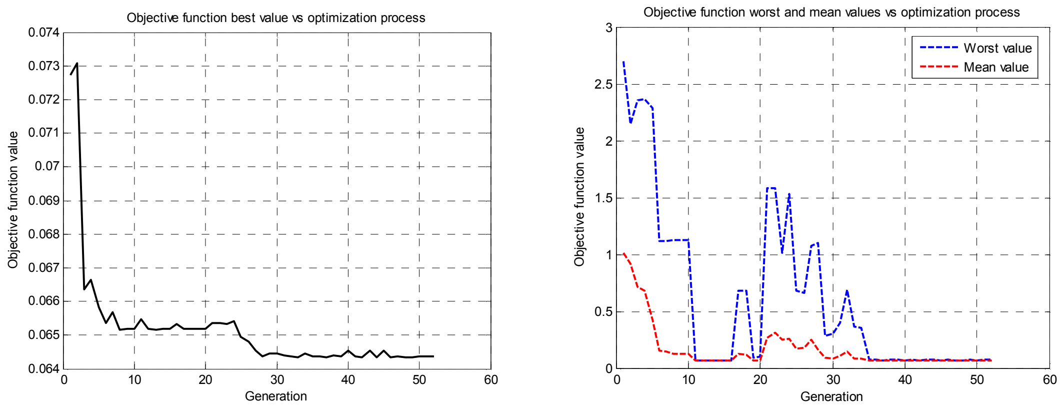


Figure 7: Optimization process vs. objective function value

The algorithm found two acceptable solutions which had the same eigenvalues but different total masses. This can be seen by analyzing the graphs presented on figure 8, in particular, total mass and fifth mode shape eigenvalues vs. optimization process. The graph of the fifth mode shape eigenvalues on the background frequency domain confirms the effectiveness of used objective function.

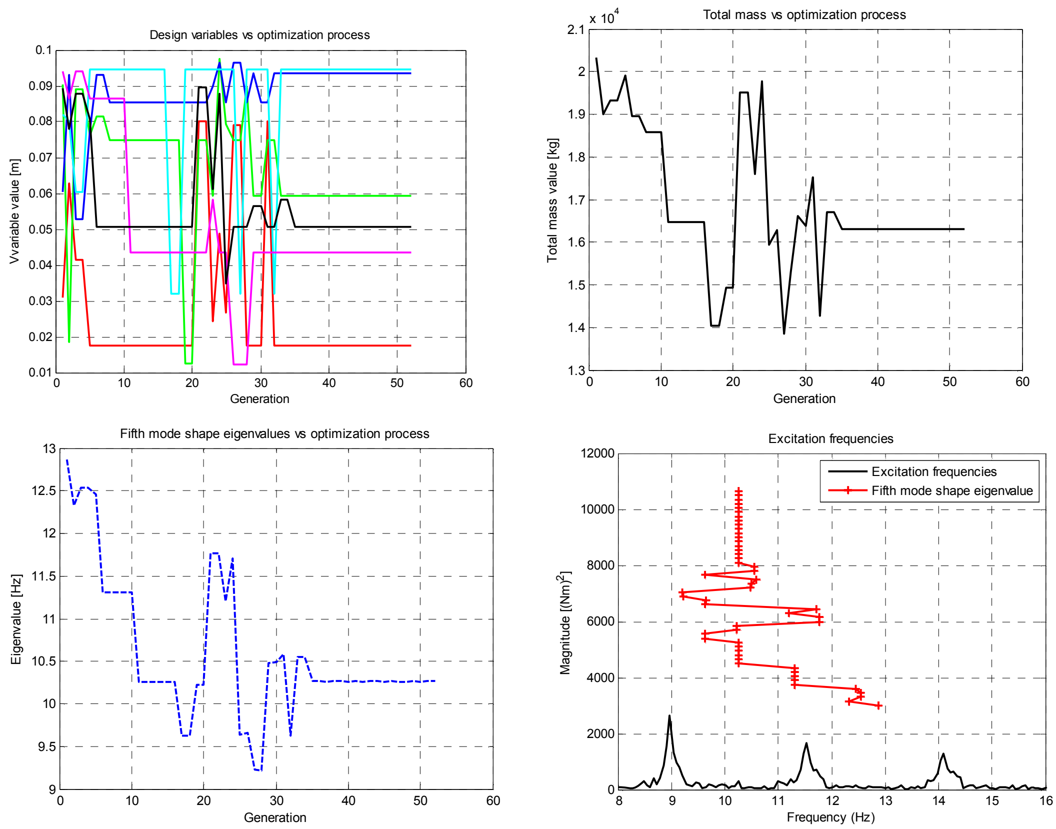


Figure 8: Results of optimization process

5. CONCLUSIONS

The paper presents methodology of modal parameters optimization of roadheader structures. The objective function application, which was described earlier, gave good results. Total mass of cutter boom decreased to 16.4 tons and the highest distance of fifth eigenmode from peaks referred on figure 1 was received. In earlier attempts of optimization, in objective function there was a lack of mass influence and the model total mass after optimization was about 20 tons. In optimization process there was the assumption that design variables x1 to x6 can change from 0.01 m to 0.1 m, without checking if strength of the cutter boom is sufficient. Also the amplitudes of eigenmodes were neglected in objective function. In the next step the objective function should include some constraint or some coefficient which will take into consideration the amplitudes of eigenmodes and stress values. This additional processes must be included in the optimization, which will increase the calculation time but give more complex model of cutter boom. The chosen design variables are the thicknesses of specified parts. They are good to show the methodology of optimization. The number of design variables in parametric model can increase and the character of design variables can change, for example, characteristic lengths and distances.

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MODELLING CONSTRUCTION INNOVATION CONSTRAINTS: A TOOL FOR SUSTAINING INNOVATION IN PROJECTS

Dr Martina E Murphy
University of Ulster, Newtownabbey, Northern Ireland, BT37 0QB m.murphy@ulster.ac.uk

Professor George Heaney
University of Ulster, Newtownabbey, Northern Ireland, BT37 0QB sg.heaney@ulster.ac.uk

Professor Srinath Perera
Northumbria University, Ellison Place, Newcastle, NE1 8ST srinath.perera@northumbria.ac.uk

Abstract

There is concern that the construction industry lacks the ability to effectively sustain product innovation through the project process. A review of literature identifies lost opportunities where product innovations were introduced into construction projects but poorly managed, thus not fully implemented. Whilst literature points to project constraints for this failure it is proposed that the problem lies rather in the failure of stakeholders to adequately manage the constraints.

Previous construction innovation research has failed to substantially evaluate and priortise constraints in implementing innovations into projects thus leading to a gap in knowledge of how Project Managers might manage these constraints to ensure successful adoption of the innovation. This paper presents a methodology for quantifying and modelling innovation constraints using FMEA and Perceptual Mapping techniques.

An iterative grounded theory approach was used to identify constraint data from 30 case studies of construction projects where a product innovation was introduced. Constraint data was extracted and quantified from the case studies using content analysis and Failure Mode and Effect Analysis (FMEA). The resultant data was subject to manipulation using perceptual mapping techniques to formulate an Innovation Management Flowchart (IMF) and Constraint Classification Matrix (CCM). These outputs map the critical management tasks with the appropriate stakeholder responses to determine the optimum workflow sequence required to successfully implement an innovation into a construction project.

A key attribute of Perceptual Mapping is that it can communicate both qualitative as well as quantitative information thereby enabling the outputs to be used by non-academic beneficiaries. The benefit of this research is an established methodology and communication framework which can be used by Project Managers to inform the risk management strategy for their projects.

Keywords: FMEA, innovation constraints, perceptual mapping, procurement, product innovation.

1. BACKGROUND

Currently the accepted means of adopting and managing innovation in construction projects relies largely on project management techniques (Bresnen and Marshall, 2001; Walker, 2007). However an over-reliance on strict project controls and evaluation methods, around which project management operates often stifles innovation (Koskela and Vrijhoef, 2001). Whilst literature points to project constraints for this failure it is proposed that the problem lies rather in the failure of stakeholder competencies to adequately manage the constraints (Murphy et al, 2011).

Rosenberg (1982) proposed that since most innovations turn out as failures more attention needs to be paid to the evaluation of innovation constraint risk. Constraints can produce a blockage in the overall project process and premature rejection of an innovation (Koskela and Vrijhoef, 2001). Constraints which act upon the project process are well documented in literature but those which act on an innovation are less well investigated (Zou, et al., 2007). Identification and prioritisation of constraint risk is therefore critical to a study on construction innovation in projects.

This paper proposes a new approach to evaluating the source of innovation constraints and presents a methodology for quantifying and modelling these constraints using FMEA and perceptual mapping techniques to develop a risk management strategy for use by Project Managers (Zou, *et al*., 2007; Dulaimi, *et al.,* 2002; Gann and Salter, 2000a; Edum-Fotwe and McCaffer, 2000).

2. METHODOLOGY

In construction-related research there are historical difficulties in investigating construction projects over a short space of time. For this reason case studies were the primary source of data for this study (Tatum, 1989). 30 case studies were identified which represented both successful and failed attempts to implement an innovation into a construction project. The cases comprised a primary group of four cases (Group A) and a secondary group of 20 cases (Group C) in which innovation was successfully implemented. A third group (Group B) was used as a control and comprised 6 cases of failed innovation. The case study selection criterion was evidence of an attempt to adopt and implement an innovation into a project based on 5 key criteria as established from the literature: (1) Newness and uniqueness of concept (Rothwell, et al., 1976); (2) First use within the industry (Laborde and Sanvido, 1994; Harkola and Greve, 1995; Slaughter, 2000); (3) Ability to effect change to standard practice (Afuah and Bahram, 1995); (4) Derived benefits for all stakeholders (Ling, 2003); (5) Associated risk (Winch, 1998; Dodgson, 2000; Ling, 2003).

To investigate innovation in construction projects it was proposed that by mapping the investigation with the project procurement stages it would be possible to identify a common framework within which to structure construction innovation research (Murphy, et al., 2006; 2006a). Whilst studies have been carried out to link procurement systems with successful innovation, there had been scant work done to map the procurement process with the innovation process (Caerteling, et al., 2006). Murphy (2011) established a Concept Model which mapped the project procurement process with the process of innovation. The model correlated two established areas of literature: The Generic Design and Construction Process Protocol (Hughes, 1991; Cooper, *et al*., 1998; 2005) and two seminal models of innovation literature; Marquis, 1968 and Slaughter, 2000. It was proposed that by mapping the case study data with the Concept Model it would be possible to identify a systematic strategy for managing innovation in construction projects.

Case study data was collected from interviews and project documentation. Interviews were carried out with key project stakeholders namely Client, Project Manager, Designer (Consultant) and Supplier (Contractor). Structured interviews lasted between 1 to 2 hours and were recorded and transcribed. There were 96 stakeholders interviewed in total across the 30 case studies. Participants were questioned about their role, responsibility and activities relating to the adoption, implementation and management of the innovation during the project. From management literature a list of relevant documentation was compiled which comprised both written and drawing documentation: Minutes of Meetings; Product specifications; Feasibility reports; Concept sketches; Production drawings and As-built drawings. The key selection criterion for documentation was that it should include direct reference to the innovation[1]. From the documentation, evidence of innovation activity was mapped against the Concept Model to provide an accurate and chronological sequence of recorded events about the 'life' of the innovation. As constraints were identified so were the stakeholder responses to each constraint.

3. DATA ANALYSIS AND MANIPULATION

Content analysis was used to analyse the volume of raw data from the documentation and the interview transcriptions. To facilitate this, the software programmes NVIVO™ and SPSS™ were used. The resultant analysis reduced the overall data content and identified emerging and common themes. Through use of cross-matching of outcomes and internal validation the analysis produced a total of 131 verifiable constraints.

From the resultant constraints there was no indication whether one constraint was more critical to the success or failure of the innovation than another. Prioritisation of constraints was necessary particularly where there were numerous project stakeholders. To do this the extracted constraint data was subject to Failure Mode and Effect Analysis (FMEA). FMEA can evaluate the *criticality* of a potential risk. By identifying the differing constraint risks the

[1] For example, a drawing that showed the connection detail between the glazing and the roof structure, or a set of minutes, which directly addressed the delay to delivery of the glazing, from the supplier.

Project Manager can modify stakeholder competencies to more effectively manage the innovation.

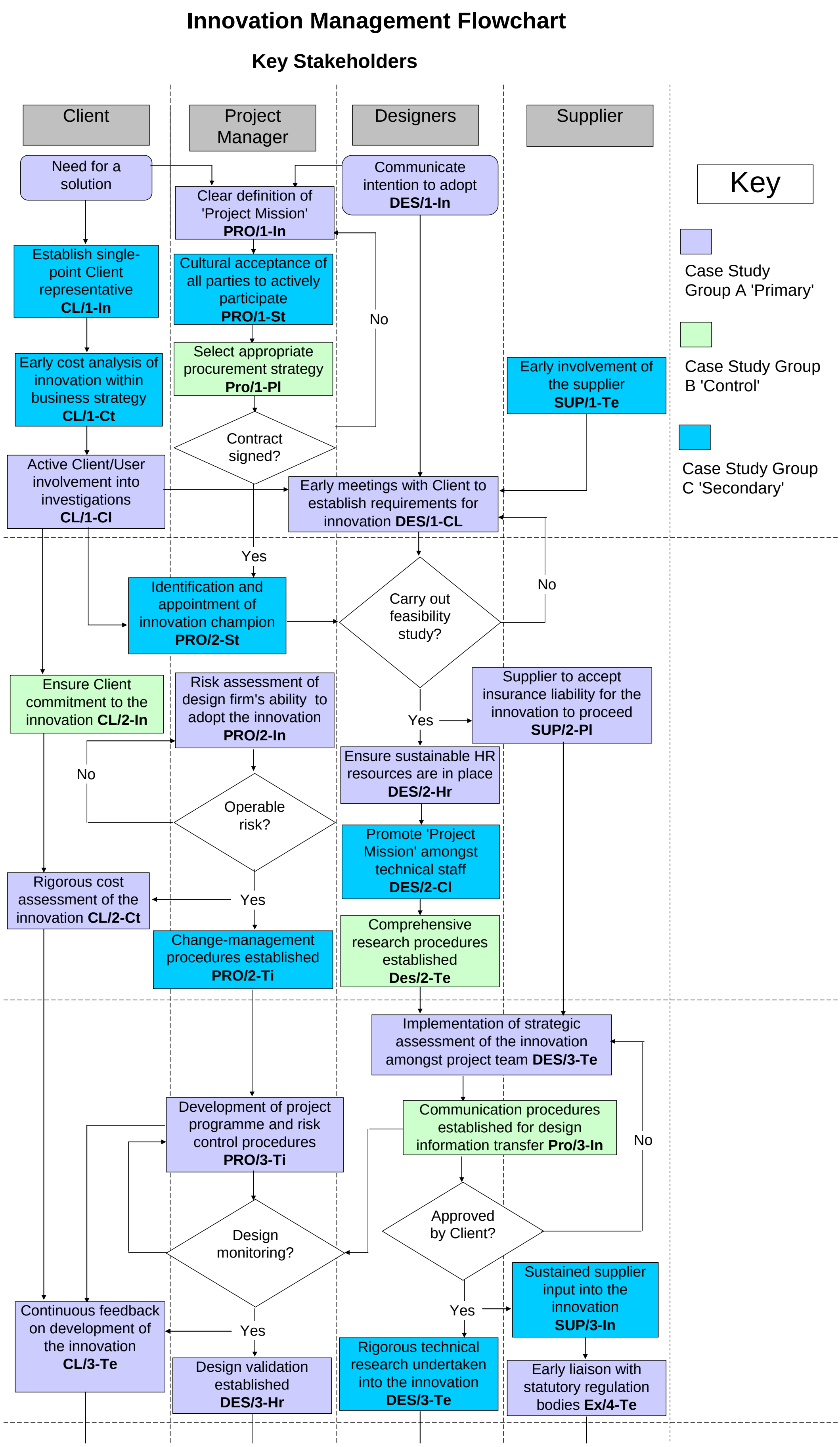
In FMEA analysis, probability is assessed by ranking the data according to probability of Occurrence (O), Severity of effect (S) and probability of non-Detection (D). The multiplied sum of these figures generates the Risk Priority Number (RPN). By identifying the 'risk priority' of a constraint, actions can then be prioritised based on the RPN value; the higher the RPN the more urgent the action required; the lower the RPN the least urgent. An RPN was assigned to each constraint identifying it as a High, Medium or Low constraint risk (Murphy et al., 2011). FMEA was applied to all 30 case studies.

3.1. Perceptual Mapping

Perceptual Mapping is a communication tool used to convey information at a number of levels. A key attribute of Perceptual Mapping is that it can communicate both qualitative as well as quantitative information simultaneously. Hence it can communicate the relationship between the quantitative data of constraint risks (RPN) with the qualitative date on the stakeholder's response to those constraint risks (Stakeholder competency). The application of Perceptual Mapping was a key consideration in this type of applied research where the outputs will be used by non-academic beneficiaries.

The Perceptual Mapping techniques used for manipulating the data in this study comprised Process Flowcharts and Matrices. A Process Flowchart is a workflow management system that coordinates the execution of numerous tasks to achieve project objectives (Sadiq and Orlowska, 2000). Rolland (1998) described a flowchart as a "rough anticipation of what the management process will look like". A Process Flowchart was formulated which mapped the Project Stakeholders (Axis X) with the Stages of Procurement (Axis Y). At the intersection of the two axes was the constraint and the stakeholder response used to manage that constraint.

The Process Flowchart data was those constraints extracted from the Groups A and C which represented projects with successful innovation. The flowchart therefore defined a skeleton of workflow tasks which could be used to successfully manage an innovation and was subsequently labelled Flowchart XZ. A second Process Flowchart was formulated using the data from Case study Group B which represented projects with failed innovation; Flowchart Y. It was observed that whilst Flowchart Y exhibited largely similar processes to Flowchart XY they were identified at later stages in the procurement process. This suggested that possible 'firefighting' or defensive management responses by stakeholders were implemented too late in the project to mitigate failure of the innovation. It was proposed that by combining Flowchart XZ and Flowchart Y it would be possible to identify those management activities which require high prioritisation at an early stage in the procurement process and those which are more effectively managed later in the process. The combined flowchart produced the Innovation Management Flowchart (IMF) (Fig. 1).


Innovation Management Flowchart
Key Stakeholders
Client
Project Manager
Designers
Supplier
Key
Case Study Group A 'Primary'
Case Study Group B 'Control'
Case Study Group C 'Secondary'
Need for a solution
Clear definition of 'Project Mission' PRO/1-In
Communicate intention to adopt DES/1-In
Establish single-point Client representative CL/1-In
Cultural acceptance of all parties to actively participate PRO/1-St
No
Early cost analysis of innovation within business strategy CL/1-Ct
Select appropriate procurement strategy Pro/1-Pl
Early involvement of the supplier SUP/1-Te
Contract signed?
Active Client/User involvement into investigations CL/1-Cl
Early meetings with Client to establish requirements for innovation DES/1-CL
Yes
Identification and appointment of innovation champion PRO/2-St
Carry out feasibility study?
No
Ensure Client commitment to the innovation CL/2-In
Risk assessment of design firm's ability to adopt the innovation PRO/2-In
Yes
Supplier to accept insurance liability for the innovation to proceed SUP/2-Pl
Ensure sustainable HR resources are in place DES/2-Hr
No
Operable risk?
Promote 'Project Mission' amongst technical staff DES/2-Cl
Rigorous cost assessment of the innovation CL/2-Ct
Yes
Change-management procedures established PRO/2-Ti
Comprehensive research procedures established Des/2-Te
Implementation of strategic assessment of the innovation amongst project team DES/3-Te
Development of project programme and risk control procedures PRO/3-Ti
Communication procedures established for design information transfer Pro/3-In
No
Design monitoring?
Approved by Client?
Sustained supplier input into the innovation SUP/3-In
Yes
Continuous feedback on development of the innovation CL/3-Te
Yes
Design validation established DES/3-Hr
Rigorous technical research undertaken into the innovation DES/3-Te
Early liaison with statutory regulation bodies Ex/4-Te

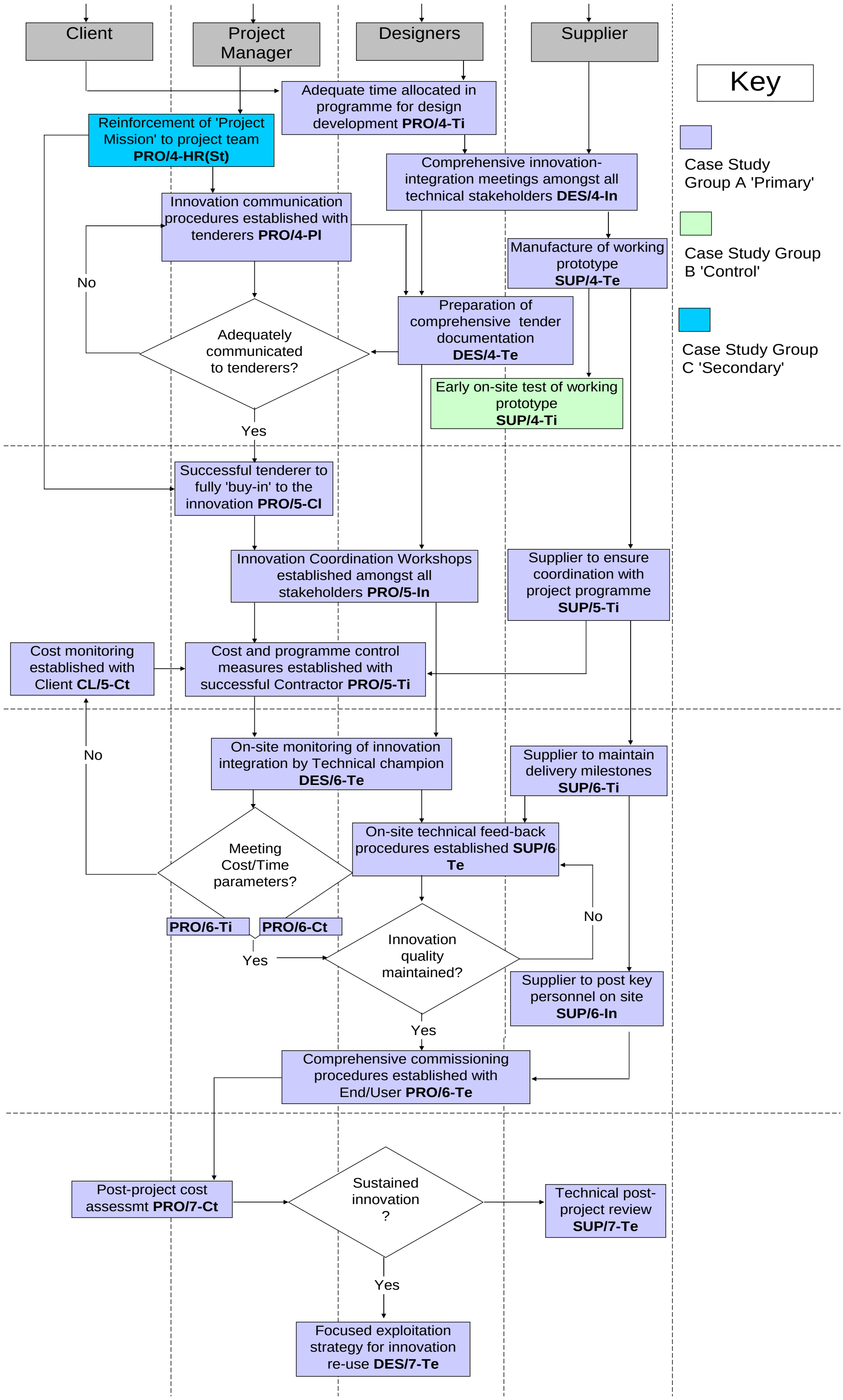


Figure 1: Innovation Management Flowchart

3.2. Innovation Management Flowchart

The Innovation Management Flowchart (IMF) established a workflow process which mapped stakeholders and their management tasks with the procurement stages of a project, to deliver a successful innovation. Initial findings from the IMF evidenced that many of the activities used to manage an innovation was drawn from the Group A data (Primary data) and this was validated by Group C data (Secondary data). These same activities are evidenced by the Control data (Group B) however they are concentrated in the mid to later stages of the procurement process. This would indicate that whilst the correct management activities took place in the failed case studies they occurred too late in the project to redress the imminent failure of the innovation.

However, it was not possible from the IMF to determine which tasks were more critical to the success of an innovation than another. The disproportionate emphasis on one particular management response at any stage may adversely impact the success of an innovation. It was proposed that the tasks identified in the workflow process needed to be weighted relative to their importance in the workflow process and to map this back to the relevant stakeholder implicit in its management. To do this a form of matrix modelling was introduced as part of the Perceptual Mapping process.

3.3. Constraint Classification Matrix

A matrix is more often associated with concepts of linear algebra and mathematical theory. It is a tri-variable communication tool in which there is an X and Y variable and where the two variables intersect there is a third variable i.e.: Z. This third variable is more often an empirical value which quantifies the relationship between the intersecting X and Y variables.

In this study a matrix was formulated in which the X Axis represented the Stakeholders and the Stages of Procurement at which they were active and the Y Axis represented the competencies of those stakeholders implicit in the management of the innovation. The Z variable represented the RPN of the constraint encountered by that stakeholder at that stage. To graphically represent the intersecting data the RPN values were displayed in the form of a bubble marker. Bubble Graphs are a form of Perceptual Mapping and provide a 3-way representation of data so that three sets of values can be compared graphically. The size of the bubble marker was scaled proportionately to the constraint risk and colour coded thus: Low constraint risk (green); Medium constraint risk (blue); High constraint risk (orange); Severe constraint risk (red). The resultant Constraint Classification Matrix (CCM) is a collective series of bubble graphs which represent the empirical constraint data across all the procurement stages and the implicit stakeholder competencies (Fig. 2).

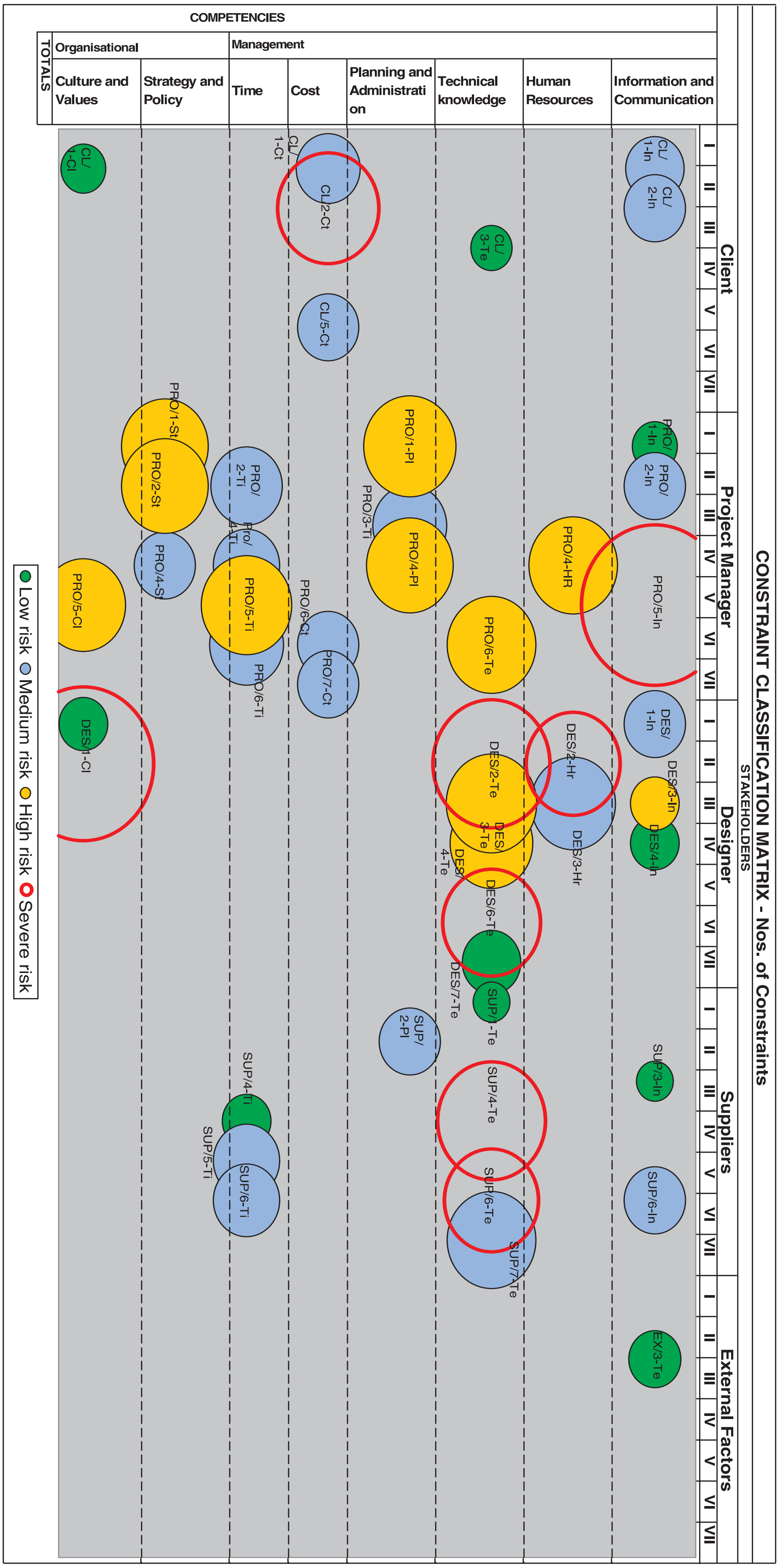


Figure 2: Constraint Classification Matrix

4. CONCLUSIONS

The study established a methodology for the analysis and modelling of innovation constraints extracted from 30 construction projects and their stakeholder responses. FMEA was used to identify the criticality of constraints and Perceptual Mapping techniques were used to manipulate the data and formulate a structured workflow process.

The study was based on the hypothesis that successful innovation in projects is largely determined by effective stakeholder management and effective stakeholder management is determined by having the right stakeholder competencies in place at the appropriate procurement stage in the project process.

From the overall study of innovation from 30 case studies of construction projects a total of 131 constraints were identified. The primary constraints evidenced were: (1) Inappropriate culture and context; (2) Poor communication between project participants; (3) Lack of technical competency of innovation champion. Whilst these constraints have been variously confirmed in previous literature, this study ranked their criticality, using FMEA, against the project procurement stages in which they occurred and identified the failure in stakeholder competency which generated the constraint.

The study used Perceptual Mapping techniques to manipulate this constraint data and generated two inter-related study outputs; the Innovation Management Flowchart (IMF) and the Constraint Classification Matrix (CCM). The IMF established a systematic workflow process for the successful management of an innovation and the CCM established the appropriate stakeholder competencies required during the process.

Previous research into construction innovation had focused on the use of established project management techniques to manage innovation (Slaughter, 2000; Bossink, 2004; Winch, 2010). This study identified that a stakeholder-centred approach is required where successful innovation delivery is incumbent on the right stakeholder competencies being in place at the appropriate stage of the procurement process. It was evidenced that stakeholder competencies which successfully addressed issues of cultural context, team communication and technical competency in adopting an innovation were most likely to succeed. Furthermore, it evidenced that stakeholder responses to failing innovation were often employed belatedly *in response to* increased constraint activity rather than *as a means to* prevent constraints occurring. This validated the hypothesis that it is not innovation constraints which require management but rather the failures in stakeholder competencies.

Previous literature had documented constraints which act upon the project process but had failed to adequately quantify differing risk weightings. This study identified that prioritisation of constraints was critical to a study on construction innovation particularly where there were numerous stakeholders within the project process. The design risk assessment tool, Failure Mode and Effect Analysis was used to identify and evaluate a risk weighting for each constraint. The benefit of this study is an analysis methodology which can be used by Project

Managers in construction projects to profile constraint risk in adoptive innovations and inform a stakeholder competency-based risk management strategy for their projects.

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FRAMEWORK FOR MEASURING AND EVALUATING BEHAVIOURAL COMPETENCIES IN CONSTRUCTION PROJECTS

Maja-Marija Nahod
University of Zagreb, Faculty of Civil Engineering, Construction Management Department, Zagreb, Croatia, majan@grad.hr

Mladen Vukomanović
University of Zagreb, Faculty of Civil Engineering, Construction Management Department, Zagreb, Croatia

Mladen Radujković
University of Zagreb, Faculty of Civil Engineering, Construction Management Department, Zagreb, Croatia

Abstract

A project manager is a person between the management and technology and who takes care that engineers and researchers achieve their technological goals. Furthermore, there is a lot of evidence that projects mostly fail because of a lack of critical project management competencies (CPMC). This paper therefore seeks to find a critical set of behavioral competencies for the successful management of construction projects. In order to do this, we adopted the competencies defined by ICB 3.0 from the International Project Management Association (IPMA) and issued a survey to project management professionals in south-eastern and central European countries. The survey showed a greater significance and level of behavioral competencies for more experienced project managers. Although behavioral competencies represent a less measurable competence, the research results demonstrated they are the most relevant competencies for success in complex projects. Based on our results we suggest a framework for measuring and evaluating behavioral competencies in construction projects, which could assist companies in selecting an appropriate project manager. At the end we present some guidelines for measuring behavioral competencies.

Keywords: behavioral competencies, construction project, project manager, success, IPMA

1. INTRODUCTION

Interest in competencies in science has been increasing in recent years. It seems that seemingly technical areas are becoming closer to social areas. It is well known that everywhere there is a human factor without which there is no effective activity, regardless of the extent to which automatization has developed. Management in the construction industry (and construction projects in overall) is no exception. In order for decisions in projects to be in line with the objectives of a project, decision makers need to be competent. This means that they must have knowledge, personal skills and experience that enable them to be efficient in business environment. More and more published papers that in one way or another deal with competence are being recorded in the ScienceDirect database. In supply chain, human resource, knowledge management, behavioral science and resource management research there are more and more published works on the subject of competencies: from 12 items in 1995 to 189 items in 2012, with a constant growth tendency.

This article is a logical continuation of previously published paper and presents the results of further research. (Nahod M.-M. et al, 2013). Research conducted on the perception of competence in construction projects has shown that the behavioral competencies of project managers in construction are of the utmost importance. Behavioral competencies define the manner or way in which an employee carries out the major duties of their job. Even if they are not directly related to salary, they should be considered in evaluating overall performance, determining salary or in other human resource decisions. They are broader and relate to how someone conducts him/herself in general.

When the dependence among competencies is taken into consideration for the perception of competence in successful projects, the greatest significance continues to be attributed to behavioral competencies (see fig.1).

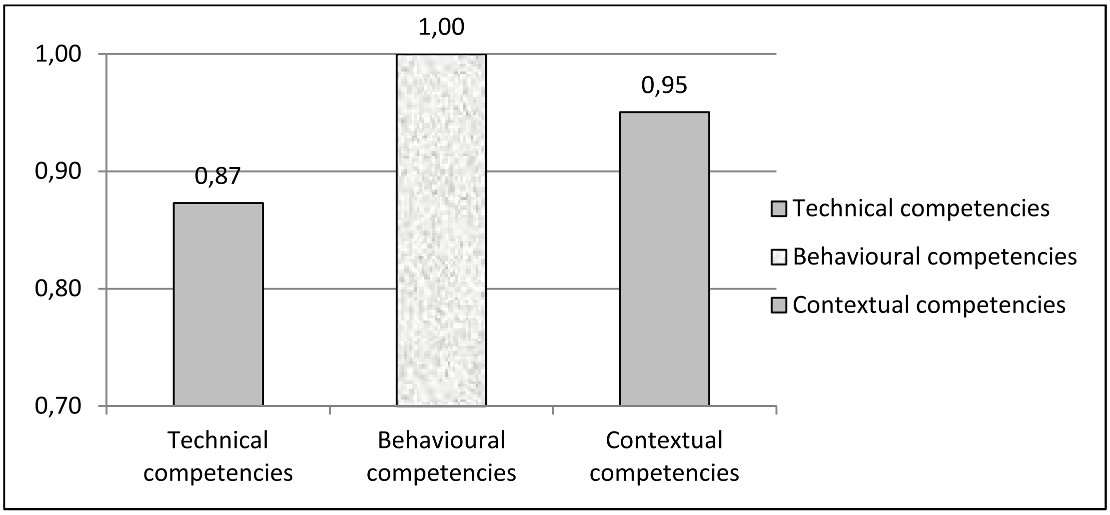

Figure 1 Perception of competencies' importance in construction projects

Connections between all competencies have been analyzed and through detailed analysis relatively independent competencies have been found, which makes the basis for this research.

2. BEHAVIORAL COMPETENCIES SELECTED FOR RESEARCH

From a detailed analysis of the defined relationships according to IPMA, openness, relaxation, creativity, reliability and ethics are obtained as relatively independent competencies on which others depend (see fig.2). The focus of the paper is on these selected competencies.

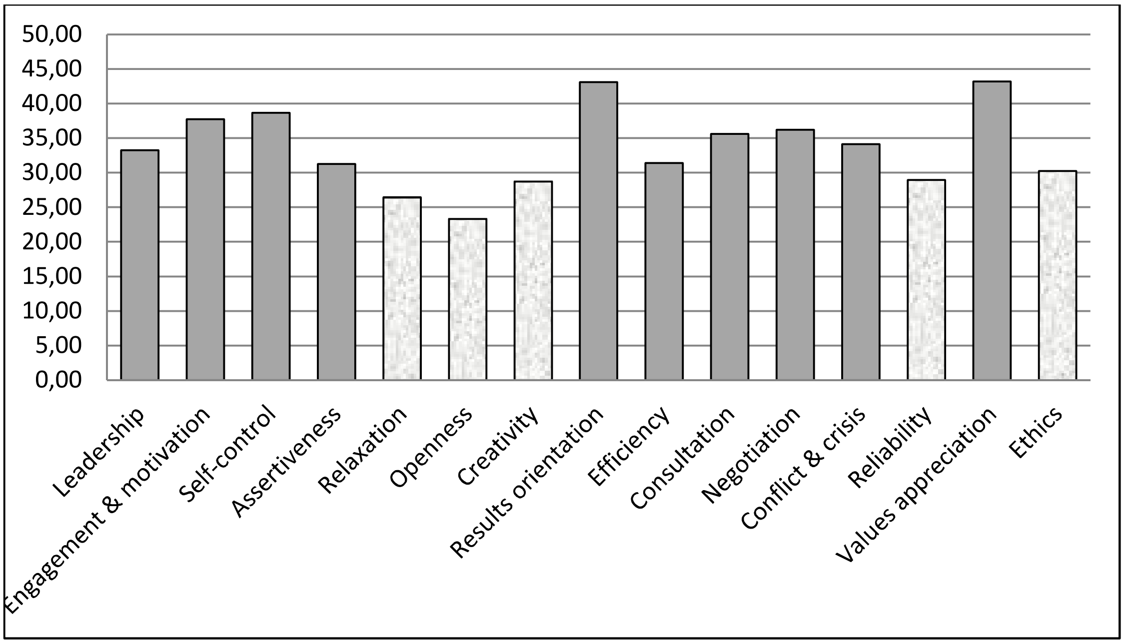

Figure 2 Independence of behavioral competencies

Openness is an empirically derived dimension of personality that reflects individual differences in the ability and tendency to seek, detect, comprehend, utilize, and appreciate complex patterns of information, both sensory and abstract. It is the ability to make others feel they are welcome to express themselves, so that the project can benefit from their input, suggestions, worries and concerns (IPMA, 2007).

Relaxation means refreshment of body and mind. Regardless of the stress that project stakeholders are faced with, they need to have built-in coping mechanisms that enable them to deal with it appropriately. It assures more calm, assertive and capable reactions and emotions and it has to facilitate everyday business and private life.

Creativity is defined as the tendency to generate or recognize ideas, alternatives, or possibilities that may be useful in solving problems, communicating with others, and entertaining ourselves and others (Franken R.E., 2007). Einstein said that creativity is seeing what everyone else has seen, and thinking what no one else has thought. It includes original thinking and manifesting innovative ideas into reality.

Reliability is the ability of a person or system to perform and maintain its functions in routine circumstances, as well as hostile or unexpected circumstances. As construction projects are very dynamic and have very demanding environments in every aspect, reliability is also a crucial competence.

Ethics or moral philosophy is a branch that involves systematizing, defending and recommending concepts of right and wrong behavior. Some of the ethical issues that one may face in construction projects include the admission of wrongdoing, focus of blame, and difficult choices regarding contracts. People handle moral problems in different ways. Psychological theory and research (Kohlberg L., 1985; Piaget J., 1932) differentiate between two moral functions, heteronomy and autonomy, which determine a person's ability to handle moral problems.

In psychological terms, ethical competence is defined as a cognitive ability, described as autonomy.

The factors that characterize a person with an autonomous way of thinking are (Kavathatzopoulos I. and Rigas G., 2006):

– The person is constantly searching for different ways to solve problems and questions every relevant value or interest

– The person reconciles his/her own goals and feelings with the interests and feelings of the other party involved in the situation: organization, team, society, etc.

– The person has a strong sense of responsibility in respect of every decision

– The person questions decisions

– In every autonomous decision there is uncertainty about what could happen

– Probabilities vs. facts: “It may happen like this” rather than “This is the only way”

– General moral principles are not applied in an indiscriminate way

In summary, an autonomous person considers and analyzes critically and systematically all relevant values in a moral problem situation. When one is confronted with a challenging problem/situation, one can deal with it either in a heteronymous way or in an autonomous way. What the use of the autonomous tool achieves is the blocking of heteronymous thinking by providing a structure for the exhaustive investigation of all relevant ethical aspects in the problem at hand (Erlandsson M. and Kavathatzopoulos I., 2005). From an autonomic ethics point of view, the person is him or herself a moral lawmaker. Action has a root in duty. In other words, every person can get himself/herself to do what is right, thus achieving a moral act.

On the other hand the factors that characterize a person with a heteronymous way of thinking (Kavathatzopoulos I. and Rigas G., 2006) are:

– The person accepts general moral principles (moral rules) without questioning them

– Thinking is an automatic reflex and the person makes uncontrolled decisions and reacts automatically to a moral problem

– General moral principles or the authorities, or both are accepted

– The person attempts to avoid responsibility for consequences and tries to place it on something external: a general principle, a counterpart, authority, traditions, etc.

– In every heteronymous decision, certainty, not doubt, is expressed

In summary, a heteronomous person does not use functional problem-solving strategies, that is, critical thinking (Kohlberg L., 1985; Piaget J., 1932). In heteronomic ethics, the root of morality is outside of the person. Decisions to act are based on environment determinations and the environment determines how someone behaves. In this way, person is achieving only legal act. The point is in the source from which a person is acting.

Business ethics is the application of our understanding of what is good and right to institutions, technologies, transactions, activities, and pursuits which we call “business”. (Velasquez M., 1994). To make decisions in the business world as well as in every social circle, we have to be informed, to think and to consider the consequences of our decisions. To make a decision, we have to perfectly define the situation. It is not easy to apply ethical and fair criteria in companies; for example, it is not easy to evaluate a worker that steals because of hunger or to buy medicine for his sick child, even though stealing is, in theory, a reprehensible act.

These are behavioral competencies that are relatively independent and that affect other competencies and are therefore these key behavioral competencies for construction projects.

3. MEASURING COMPETENCIES

The measurement of behavioral competencies requires the measurement of attitudes and values for which it is not easy to assess the validity of the instruments applied. Measurement of these observed units can only be made indirectly - through appropriate indicators. The problem that appears when measuring such, latent, entities is to connect abstract concepts with empirical indicators and to determine the extent to which any such indicator (or set thereof) represents the given theoretical concept.

There are several models of competence that can be applied to behavioral competencies. All of these have in common that they distinguish the easily measurable and visible part from the hidden part that is difficult to measure. One of the models that clearly show this is the Competency Iceberg model, where an iceberg has just one-ninth of its volume above water and the rest remains beneath the surface of the water (see fig.3). Similarly, a competency has some components which are visible, such as knowledge and skills, but other behavioral components, like attitude, traits, thinking styles, self-image, organizational fit, etc. are hidden or beneath the surface (Spencer L. M. and Spencer S. M., 1993).

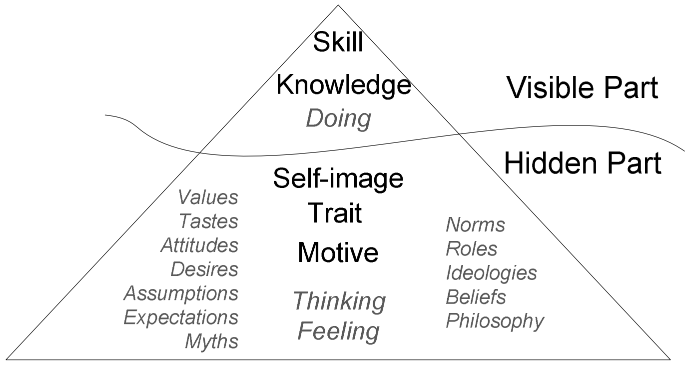

Figure 3 Competency model: Iceberg (Spencer L. M. and Spencer S. M., 1993)

Knowledge includes information from education and experience that can be used; Skill means the ability to do something well (e.g. technical skills to make use of knowledge). Self-image means how people view, identify and value themselves (e.g. an expert, leader, learner, innovator). Traits are habitual/enduring characteristics (e.g. flexibility, self-control, good listener etc.)

For measurement instruments that measure competence it is impossible to say that they are entirely valid or invalid - they can be distinguished according to the degree of their validity. The validity of measurement instruments that measure competency can be content, criterion and construct validity (Nunnally, J. C. and Bernstein I. H., 1994). Content validity represents the adequacy of the questions in relation to the topic that is the subject of the research.

A criterion validity assessment determines to what extent the results obtained on the instrument is associated with the results on another variable that figures as external criteria of validity. The degree of correlation between the results on the instrument and the criteria is the only relevant indicator of the criterion validity of the instrument.

4. RESEARCH METHODOLOGY

To date, studies have not been conducted on the standardization of a questionnaire for the purpose of a complete and objective psychological expert assessment of the degree of competitiveness on construction projects. The research conducted is the starting point in developing a questionnaire to standardize measurements of behavioral competence in construction projects. The competencies that are essential for construction projects are found and a pilot study has been carried out to verify the content validity of the questionnaire.

The main research methodology is a questionnaire. In addition to detailed insight into the state of the selected competencies, the perception of the importance of behavioral compared to other competencies is confirmed once again.

The conducted questionnaire has content validity because it is suitable for all the specifics of the given themes, criterion validity is confirmed through association with the results of already published survey and forms its further development, while construct validity as the degree to which the result of the questionnaire focuses on the specific feature is yet to be proven in the subsequent research, which will be carried out through standardization of the questionnaire. Therefore, in this paper we have conducted a secondary analysis of data collected through the questionnaire adapted for other purposes. The steps in the research are presented in the following figure (see fig. 4):

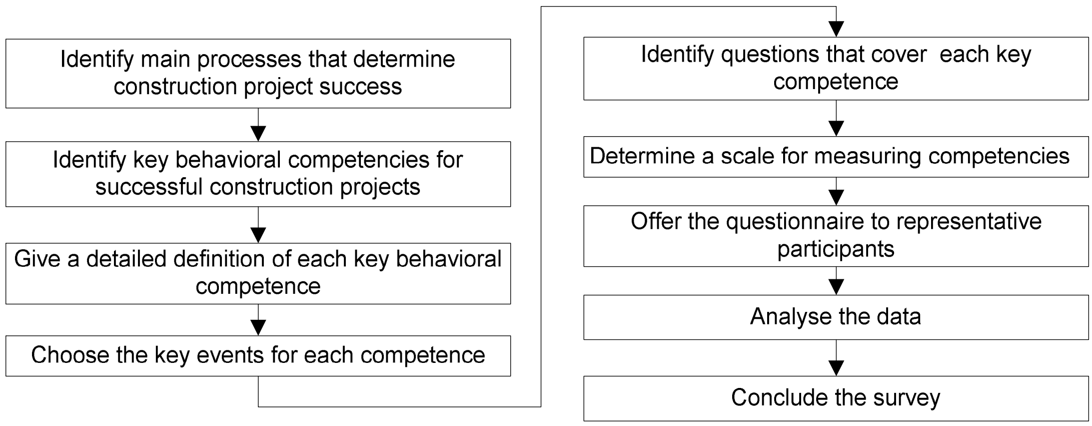

Figure 4 Parts of conducted research

In this research the results of questionnaires collected with the aid of three measurement instruments have been used: FIRO B Questionnaire for openness (Schutz W., 1992), ESCQ (Takšić V. et al, 2009), Emotional Skills & Competence Questionnaire (ESCQ) and Key Event Questions for ethical problems and evaluations. The issue of the study is how participants think and not the way they solve those problems. The important fact is the process of making a decision and not the specific decision.

A high degree of similarity was found between key event questions arising from the research into the state of construction projects and 10 (of 50) questions from the Ethical Competence Questionnaire-Working Life and Business (ECQ-WLB) (Kavathatzopoulos I. and Rigas G., 2006), which is why these questions have been applied (case questions, that represent key event questions). The issue of study is not the solutions the participant offers to the moral problems, but how the participant thinks. The facts that a participant thinks are important to consider before any decision is made. The focus is on problem-solving and decision-making.

The task of the participant is to place himself/herself in the position of the main character of the dilemma and to mark which of the alternatives he/she considers to be the most important to take into account before solving the problem. There are different solutions to the same situation and it is therefore necessary to make a personal deliberation, influenced by the organization's or the society's deliberation. Here is where ethics must be applied. (Tierno Gismera L., 2003).

The study consists of 22 questions and a total of 73 particles. The first 8 questions relate to general information about the profile of the respondent, his experience and work to date. Then, the participant is asked about perceptions of competence and through the last 13 questions 64 particles are given that represent key behavioral competencies for construction projects.

Research was carried out on 42 respondents consisting of 24 consultants (57%) and 18 contractors (43%). All respondents work in the private sector, and 28% of them have their own business. The majority (57%) work at the operational level, while 36% of respondents work at the senior management level. 86% of the respondents are male, 14% female. The age group of the respondents was relatively uniform, with 75% between 35 and 65 years old. More than 50% of the respondents have more than 10 years' experience in construction projects. 43% of the respondents did not wish to clarify their geographical position, 36% were from western Europe and 21% from eastern and south-eastern Europe. 42% of the respondents are involved in residential and commercial building construction, while 43% of them work on heavy civil construction projects.

An analysis was performed according to each criterion of division, but the representative sample is relatively small and the conclusions related to specific groups of respondents carry this limitation.

5. RESULTS

After a detailed analysis, the results are summarized in two groups: respondents who work in south-eastern Europe and respondents who work in western Europe.

As in the previously conducted research, behavioral competencies are perceived as the most important (in 58% of responses), followed by technical (36%) and contextual (6%). Two groups showed no difference in the perception of the importance of the competence.

The results from western Europe showed negligible differences in the indicators of openness, relaxation, creativity and reliability - the percentage of desired responses from a business point of view is a total of 77% for western and 73% for south-eastern European participants. A somewhat greater difference appears in the results related to ethical competence, where western European participants have 61% and south-eastern European participants have 40% of the business desired responses from a business point of view.

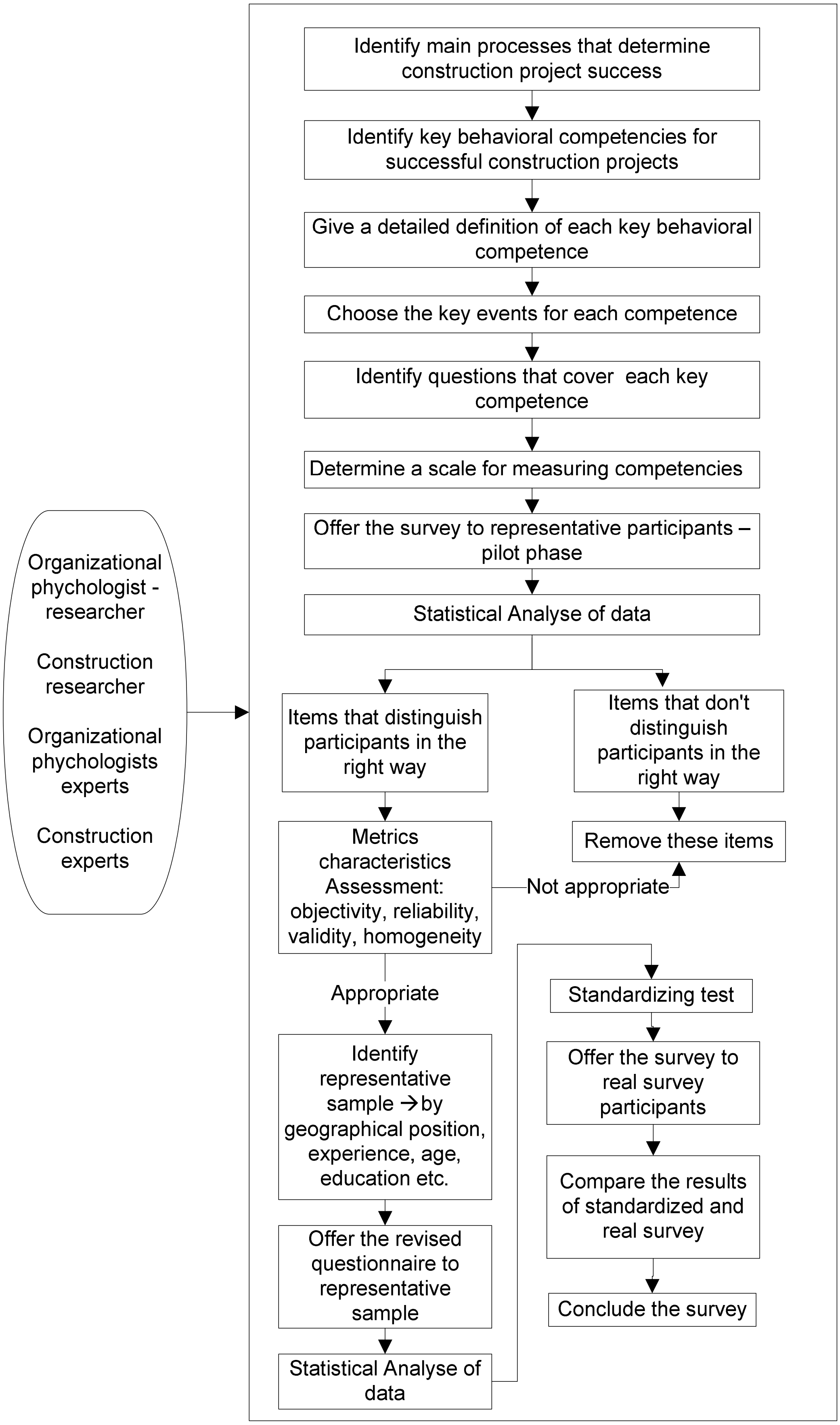

Figure 5 Framework for measuring and evaluating behavioral competencies in construction projects

6. CONCLUSION

The field of competence measurement and research is relatively new and under-explored in construction projects. Previous studies have identified key competencies but there are no standardized tests to objectively measure these competencies. The identification of relatively independent competencies which, however, do depend on each other, represents the key set that must be the focus of instruments for measuring these competencies. For the development of such instruments the engagement of multidisciplinary experts in psychology and construction is required. A graphical representation of a framework for measuring and evaluating behavioral competencies in construction projects is provided on fig.5.

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INCREASING DURABILITY OF CONCRETE BY NANOTECHNOLOGY AND BIOTECHNOLOGY MATERIALS FOR SUSTAINABLE DEVELOPMENTS

Mohammadreza Nejati
Abadgaran group (Construction Chemical Manufacturer), Tehran, Iran, m.nejati@abadgarangroup.com

Behzad Abbasnejad
Chalmers University of Technology, Gothenburg, Sweden, behzada@student.chalmers.se

Abstract

Concrete as a macro material is affected strongly by its nano features. Understanding concrete behavior and structure performance in nano and micro scales improves and promotes concrete characteristics and also construction and production of concretes proportional to today requirements. In concrete industry, nanotechnology has proved to improve fundamental specifications of concrete including strength, durability, lightness, flexibility and impenetrability and also to construct intelligent aggregates and improved cements, production of concrete with ability of high thermal and sound insulations, self-cleaning and self-healing. Continuous researches disclose secretes regarding this industry. Improvement of concrete age is one of main objectives of concrete industry in long term. using nanotechnology in production of concrete and intelligent healing in failure without human intervention are of new and under developing achievements in concrete industry and it accompanies with longer age of concrete structures in direction of sustainable development and environmental protection. Self-healing system of concrete is simulated by defense system of organisms while repairing damaged parts so after identifying damages, concrete structures self –heal themselves by aid of materials. One of these methods is used in construction of self-healed concrete by aid of bacteria available in the nature that are able to live in high alkaline medium of concrete. This bacterium is called Bacillus which is able to live longer in lakes with high alkaline property in Russia and Egypt. In this paper, the newest self-healing methods of cracks in concretes will be described using nanotechnology and biotechnology.

Keywords: Biotechnology, concrete industry, nanotechnology, self-healing, useful life.

1. INTRODUCTION

Nanotechnology as a new technique and approach to materials with controllable properties in nanoscale has many applications in different fields such as medical science, electronics and building industry. By entering to area of atoms combination and molecular interactions, it attempts to arrange molecules based on its desire in order to reach required behavior from the combination. Professionals of nano science believe that after production of steam engines and Information Technology development, nanotechnology opens new horizons to current world. Importance of nanotechnology in the industry with sustainable development as a necessity to protect environment and benefits of future generations may realize goals of sustainable development with higher intensity.

Nanotechnology has entered in different areas of building industry such as metals, concrete, soil, glass, energy and optimal ventilation, water treatment, sensors, linings, dyes and insulations. In recent decade, several researches have been done on application of nanotechnology in concrete technology. Concrete as a macro material is affected strongly by its nano features. Understanding concrete behavior and structure performance in nano and micro scales improves and promotes concrete characteristics and also construction and production of concretes proportional to today requirements. Nanotechnology in concrete industry has proved to improve fundamental specifications of concrete including strength, durability, lightness, flexibility, and impenetrability and also to construct intelligent aggregates and improved cements, production of concrete with ability of high thermal and sound insulations, self-cleaning and self-healing. Continuous researches disclose secretes regarding this industry.

2. NANOTECHNOLOGY AND PROCESSES OF CONSTRUCTING SELF-HEALED CONCRETES

In nanotechnology, material sizes change into nano scale and after reconstruction, they are being delivered in the industry as materials with new properties. Different oxides such as nano-SiO2, nano-Fe2O3, nano-Al2-O3 and nano-TiO2 improve physical, mechanical properties and durability of concrete. For example, effect of activated radiation and property of self-cleaning are created along with removing air pollution. Using nanomaterials in external surfaces of buildings and roads especially in crowded areas with more prolusion reduces economical and environmental losses and it has been used in many developed countries since 2008. An example is use of titanium oxide in 7000 cubic meters of Milan roads and 60% reduction of nitrogen dioxide in the air [1].

Fig 1: using nanoparticles of TiO2 in concrete of roads in order to self-clean and reduce air pollution.

One of main issues in every concrete structure is to control and prevent cracking in sections. concrete cracking occurs internally by concrete materials or external factors and environment such as corrosive chemical media that have chloride and sulfate, penetration of salts and acids, atmospheric and environmental effects, strong weather changes and damages and loads imposed on concrete. these cracks with microscopic cracks evident in tensional part of concrete disrupt performance of concrete structure because cracks are easy ways for penetration of corrosive materials such as chlorine, salts and detrimental acids or carbonation due to entrance of CO_2 and water in the concrete so that corrosion occurs in bars resulting in deterioration of reinforced concrete member. Many researches have been done on control and healing of cracks and protection of reinforced concrete members against corrosion. At the moment, reconstruction of damaged member, different chemical linings and using materials for filling cracks are traditional and common ways of healing. Introduction of nanotechnology to concrete industry with birth of self-healing composites show construction of intelligent structures with failure diagnosis and self-healing. It seems that nanotechnology has caused realization of the first imagines of sustainable architecture pioneers including William McDonough who described concept of alive buildings. This technology is being developed inspirited from healing mechanism in organisms and it is simulated in concrete. Then the most important and efficient nanotechnology is represented in concrete self-healing along with response of self-healing to created damage.

2.1. Using bacteria to construct self treated concretes

This method is used by aid of bacteria present in the nature which are able to live in high alkaline medium of concrete and it is used for construction of self-healing concrete. This bacterium is called Bacillus which is able to live longer in lakes with high alkaline property in Russia and Egypt. These bacteria with their feed source are embedded in small ceramic pellets and they are suspended in concrete water in order to prevent sudden activation in wet concrete mixture. Bacteria stay in concrete in a pre-activated and dormant form until crack formation. Then it is activated due to crack extension and water penetration, solid calcium carbonate deposits due to reaction of bacterium with concrete combinations and crack pores are closed by this sediment [2,3]. Fig 2 shows self-healing mechanism using bacteria.

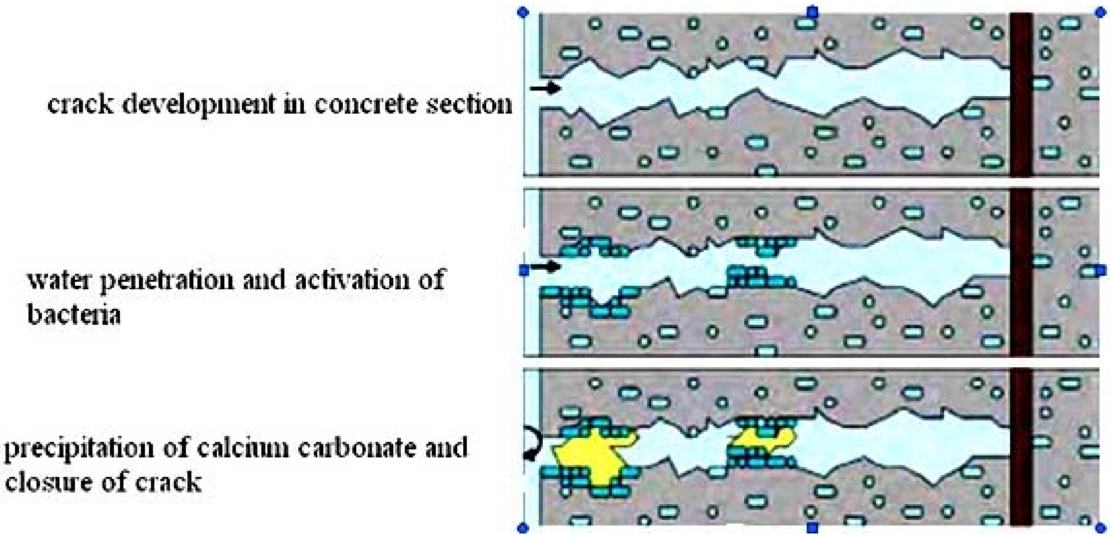

Figure 2: healing failure using bacteria

Researches still are continued to choose suitable bacterium with ability of staying alive and activated in concrete medium and during exploitation and it should have the least negative effect on concrete behavior and strength. It should be noted that before discovery of this bacterium, bacterium mineral products were used to heal concrete cracks. It was not effective due to manual placement of bacteria in damaged site by human force and production of toxic ammonia and also due to reaction of bacteria with concrete compounds.

2.2. Using micro-capsulated healing agent

In this method inspired from role of red blood cells in coagulation and healing, microcapsules containing healing agent are injected into concrete. Microcapsules containing healing agent are made of polymer particles embedded into a capsule with catalyzer lining in the body. Microcapsule breaks after contacting with crack and polymerization is done next to catalyzer so the crack is healed by forming stiffen materials [4]. In fact as red blood cells and catalyzer, circular microcapsules simulate role of platelets in coagulation while healing lesion on skin. Fig 3 shows healing mechanism of failure by microcapsule system.

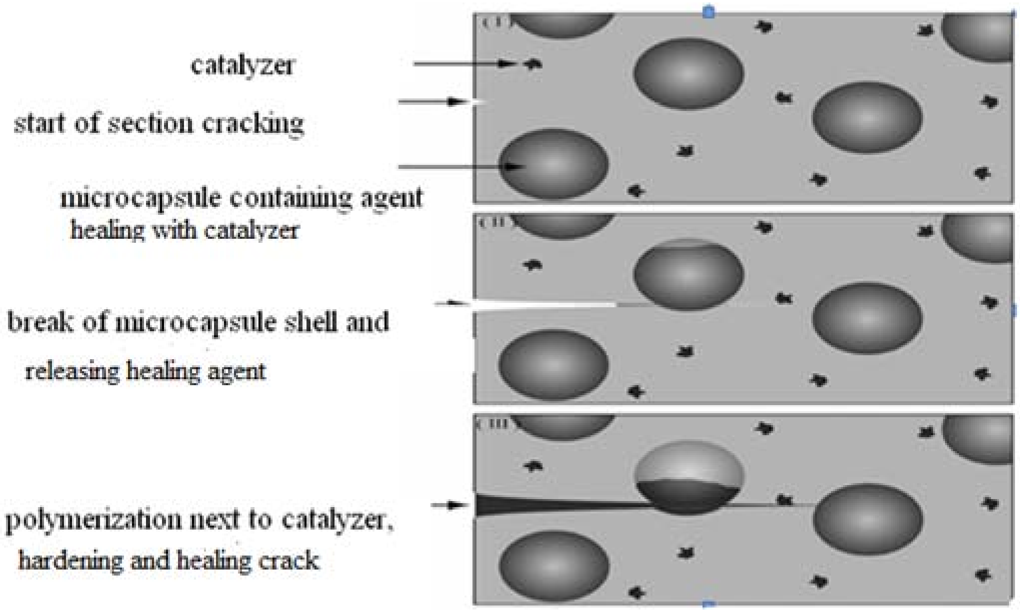

Figure 3: mechanism of action of microcapsules in healing crack

In this method, increase of microcapsules affects homogenous and uniform concretes and reduces toughness of concrete. Therefore, healing agent should be injected by an intelligent system in order to improve performance. Recent researches suggest placement of microvascular network and transfer of healing agent from source to failure based on capillary property, polymerization next to catalyzer, formation of a hard material and crack heal. Future researches are going to develop an intelligent microvascular network in concretes containing healing agent like biologic systems[5].

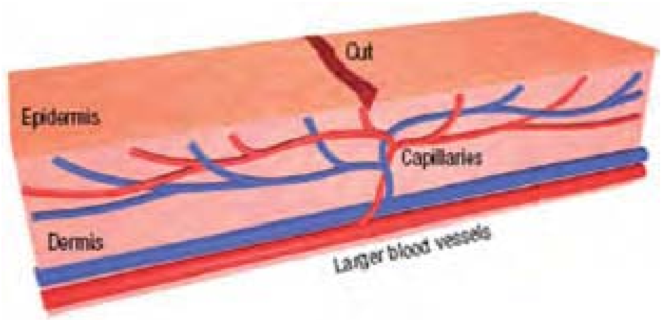

Figure 4: micro vascular network in order to develop and place microcapsules inspirited from biologic system.

2.3. Selective heating method

At present, the most efficient and intelligent self-healing system is selective heating system. It consists of two main parts:

1. self-diagnosis composites that are made of fibers and electrically conductive materials. It has capability of a strain gauges and also it can record time history of failure in the structure.

2. Healing part

Heat-plasticity organic film pipe is made of materials with plasticity against heating and they contain healing agent so that they prevent healing agent before expansion of crack.

When a crack occurs, the first part identifies partial strain in crack, acts as a sensor and sends a message to healing agent (such as neurons in body of animals), healing agent is released and heals the crack. Mechanism of sending message is due to cut off in damaged area and increase of electrical current resulting in increase of temperature and melting shell in which healing agent is placed[6]. Designing this system is very sensitive because it uses thermal energy to release healing agent so that increase of temperature in concrete should not result in evaporation of internal water and collapse of internal structure or any process detrimental to toughness properties of concrete. Fig 5 shows healing process by this method. This system in complete form can control and represent degradation process outside the structure by monitoring diagnostic information that is a great change in concrete healing industry in sensitive structures.

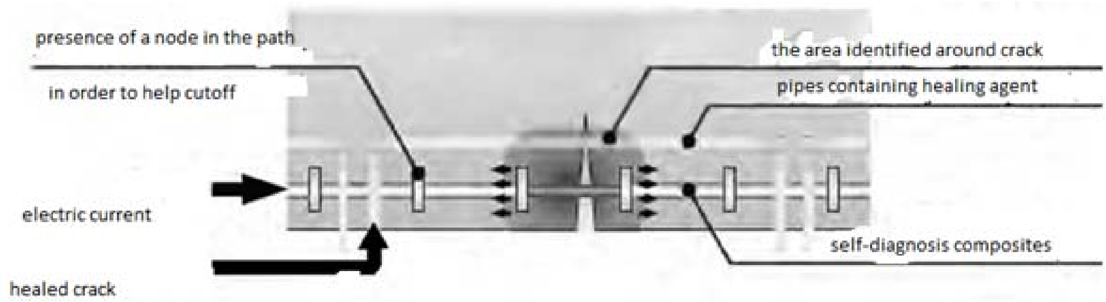

Figure 5: mechanism of healing failure in selective heating system

2.4. Self-healed concrete using engineered cementitious composite (ECC)

Performance of concretes that are made using ECC is inspired from improving lesion of organism that by healing cracks continuously, crack expansion and creation of crevasse are not allowed even if damaged concrete part is reloaded frequently. In fact, the most important feature of ECC is that only cracks with 60 micrometer wide will be resulted close to each other instead of deep cracks in concrete. In other words, new concretes of ECC have a high flexibility compared to ordinary concretes [7]. Researches show that using pozzolan fly ash improves performance of ECC. Fly ash reacts with calcium hydroxide resulted from cement hydration and produces a white gel that is able to close hairline cracks and self-healing [8].

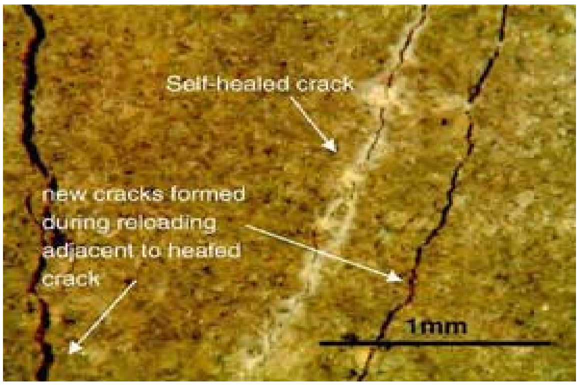

Fig 6: crack self-healing in ECC concrete and crack expansion after reloading the sample in a place other than healed site.

This dense concrete is very important for protection of reinforced concrete in corrosive environment such as those containing chlorine so that chlorine solution available in water penetrates due to micro-cracks and corrosion of reinforcements and reduction of reinforced concrete toughness.

2.5. Carbon nano tubes

Carbon nano tubes is a kind of carbon that was first discovered in Russia in 1952 but it was forgotten. This material has been regained a special place in nanotechnology. Nanotubes are produced in forms of single walled and multi walled with length of several centimeters.

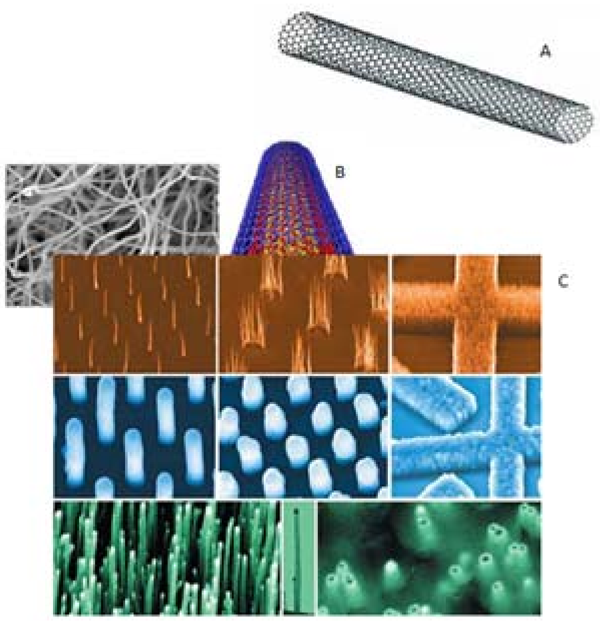

Figure 7: A) single walled carbon nanotubes B) multiwalled carbon nanotubes C) magnified CNT samples

By adding small amount of CNT to cement, mechanical properties of concrete improve considerably. These nanomaterials are used in concrete self -healing processes. There is a problem while using CNT in cement that is connection of nanotubes in form of filament and lack of enough viscosity between concrete and nanotubes [9]. Researches still continue to study how to use these materials in self-healing process.

2.6. Application of hollow fiber

In this method, using florescent colors in healing agent in these filaments simulates bruising in organisms that plays an important role in identification of injured site. In this method, healing agent releases from a fine hollow fiber to fill and heal cracks [10]. Mechanism of healing by this method is shown in fig.8.

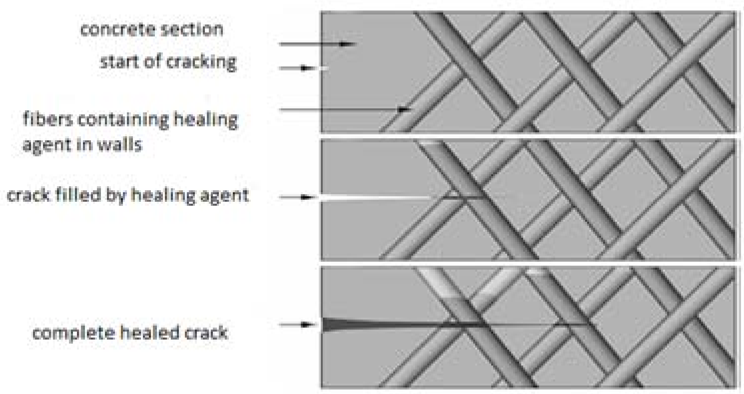

Figure 8: mechanism of crack healing by hollow fibers

3. CONCLUSIONS

Concrete industry is one of widely used industries and in recent years by representing interesting achievements resulted from nanotechnology in order to improve concrete performance and behavior, it opens an endless way in front of researchers. Self-healing process is under development by benchmarking what occurs in organisms against injuries and many self-healing methods mentioned here are still on the way. The focus of future research on concrete self-healing is to increase efficiency and combine diagnostic methods and approaches of damaged site and effective healing with the least facilities and cost. It is evident that development of these methods and application in construction industry is very effective on increase of safety and it is in direction of sustainable development. Current high costs of nanotechnology products are economically justifiable with mass production and considering return of investment in long term due to increase of structure useful life and reduction of repair costs.

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WOMEN IN THE CONSTRUCTION INDUSTRY: INVESTIGATING CURRENT CHALLENGES FACED BY WOMEN IN THE U.S CONSTRUCTION INDUSTRY

Stephanie Nielsen
East Carolina, Greenville, United States, Nielsens08@students.ecu.edu

Syed M. Ahmed
East Carolina University, Greenville, United States, ahmeds@ecu.edu

Catherine Yaris
East Carolina University, Greenville, United States, yarisc12@students.ecu.edu

Abstract

In the United States, the construction industry is stereotyped as male dominated. As we develop into a nation where women account for over half of the work force, we continue to see an imbalance of gender in construction management roles. The objective of this research is to explore the many aspects of these phenomena. The research conducted will investigate the reasons behind low female participation, the barriers women face entering the construction industry, the current status of women in the US construction industry, and the expected benefits to the construction industry with increasing levels of women's employment.

The methodology used in this research is to collect quantitative data from industry leaders through literature analysis and secondary analysis of data. This data will then be compared to historical data, data collected through informal interviews and literature reviews. The research aims to highlight challenges women face as well as potential advantages.

The barriers females face such as inequitable pay, potential harassment, lack of information available about this career option, and the male dominated environment will be investigated and explained in detail. The result of the research forms a model which contains methods to increase and retain female participation in the construction industry. The results will also shed light on the reasons behind low female participation in the construction industry as a whole. The conclusions drawn from this paper provide a set of recommendations and guidelines to increase the participation of women in the U.S. construction industry which will ultimately result in positive benefits to the entire economy.

Keywords: Female Population, Construction Industry, Construction Management, Work Force.

1. INTRODUCTION

Construction management is a male dominated industry in the United States. There are very few women reported studying, working, or even knowledgeable about being a part of the construction management industry. As the United States develops into a nation where women account for over half of the work force, the country continues to see an gender segregation in construction management roles. This is largely influenced by the image portrayed to the public about construction management. Most women would say that the first thing to come to mind when they hear construction management is "building houses, driving bulldozers, or hammering nails." What women do not know is that these tasks are actually only a miniscule part of being a construction manager.

Written in 2007, the State of Maine Department of Transportation published a booklet titled "Women in Construction, Working Group Report". This brochure states its concern for the industry and the rising urgency of increasing the female workforce. "The reasons for encouraging women in the construction trades go beyond fairness. It is an economic necessity. Our Workforce is aging. Not only are our children leaving the state, but children are not being born in sufficient numbers to replace the baby boomers. At a time when families are considerably smaller and children are encouraged to pursue college education, finding qualified employees to enter the construction trades is becoming more difficult, regardless of gender or race. The average age of a worker in the trades is now 47. Replacing this aging workforce will take ingenuity and commitment from the industry, the education system and policy makers. It is in the state's best interest to create a more diverse workforce to meet the economic challenges of the industry." (Maine, 2007)

It is very important that young men and women are aware that the construction industry is a viable and respectable career path. Also, it is important that industry leaders ensure fairness and equity will be conveyed in the hiring process and on the job. Therefore, employers, policy makers, and public officials need to enforce that everyone is treated with respect and encouragement, despite their gender, race, or religion and a no tolerance policy about discrimination will be in place.

2. OBJECTIVES OF STUDY

Increasing the number of women in the construction jobs is crucial for the growth and success of the industry. Actively pursuing a greater number of women within the industry can be simplified to a general model to obtain and retain women within the industry. The objective of this research is to develop a model which can be followed by women within the construction industry as well as industry leaders. This model will give guidelines for educational as well as professional entities to recruit women, retain women, and increase personal growth within the construction industry.

3. METHODS

The data used in this research was collected from construction industry leaders through literature analysis and secondary analysis of data. This data then was compared to historical data found from government and United States labor sources. The information collected through professional women construction organizations and government websites show the state of the industry and update of the number of women working within the industry as well as the roles played by these women. The research highlights and discusses barriers women face as well as potential advantages in being a woman in a male dominated industry. The researchers describe methods to attract women, retain their presence in the industry, and increase their standings within a company. Benefits to employers having women within the construction management industry and in the workplace are discussed briefly. The model which was generated through this research will aid both women and industry affiliates with increasing the female population. The conclusion and suggestions have been collected through informal interviews and past experiences well as data through professional women's organizations.

4. ANALYSIS

Multiple barriers and challenges have been reported for women entering the construction industry. The most common barriers and challenges faced include (A Strategic Plan to Promote Women, 2012):

- Stereotypes/ sexism/ perception of women on a job site
- Lack of information available about trades ads a career option
- Physical strength
- Lack of daycare/ difficulty with work/ life balance
- Flexibility in hours
- Male dominated environment
- Lack of mentoring programs/ networks for women

Women face several of the above listed barriers when considering a career within the construction industry. Due to the lack of knowledge of the construction industry, women feel as if a male dominated environment will lead to harassment and unfairness within the work place. Gender barriers within the United States lead women to perceive the construction industry as one in which they must have physical strength, work outside, and receive less pay. Due to this overwhelming amount of negative stereotype, women tend to be biased against the true nature of the construction world.

What women do not realize is there are educated employers in this industry who want women to be a part of their company because they know that women contribute a skill set different from men. Educated employers know that women possess skills that will bring value to companies including strong communication skills, exceptional multitasking, more conscientious, hardworking, detail oriented work ethic, well-organized, higher loyalty, lower turnover rates, above average listening skills, high willingness to learn, more compassionate personalities, etc (A Strategic Plan to Promote Women, 2012).

Therefore, it is important that the construction industry works as a whole to recruit and retain women, while at the same time educating employers about the benefits of diversifying their companies. While this may seem like an easy solution, it will require a long-term commitment from federal and state government, contractors, as well as educational and non-profit organizations.

When speaking informally with females working as construction managers the struggles which women seem to face are more directly in the construction field. The women stress the point that they do not feel as if men within the construction workplace show respect for a woman as the authority figure. This lack of respect can be extreme as male employees viewing the female owner as just the owner and not someone who should direct them or their work

There are numerous organizations whose specific aim is in support of women in construction related fields. The basic goals of these organizations are to recruit women, promote retention of women in the trades, and develop leadership and career growth among women. The organizations are known to help provide support to women in construction through training and education, networking, gathering and sharing information in the construction industry, and offering opportunities to women to advance in their field. These organizations include:

Organization	Main Focus
National Association of Women in Construction (NAWIC)	Founded as a support network. Provides members with opportunities for professional development, education, networking, leadership training, public service
Women Contractors Association (WCA)	Non-profit organization made up of female owners and executives. Networking and valuable information specific to construction industry and small business owner
Women Construction Owners & Executives USA (WCOE)	Focuses on member's business growth. Has a presence on Capitol Hill monitoring and pursuing legislation advantageous to the construction industry
Professional Women in Construction (PWC)	Committed to advancing professional, entrepreneurial and managerial opportunities for women and other "non-traditional" populations within the construction industry.
Hard Hatted Women (HHW)	Dedicated to helping women succeed in high wage, trade and technical careers. Work through volunteers, business and educational partners. Believe in economic security through the trades.

Table 1: Professional Organizations Dedicated to Helping Women

Despite organizational efforts, the gap between men and women in construction has remained quite constant in the past decade. According to the National Association of Women in Construction (NAWIC), as of December 2011 women only make up about 9% of the construction industry. The NAWIC Fact sheet (Table 2) shows the breakdown of those women in depth.

Breakdown of Women in Construction

As of Dec. 31, 2011, an average of 828,000 women were employed in various occupation sectors of the construction industry. Women now make up about 9 percent of the construction industry in the United States. The following is a breakdown of women by occupation sector in the construction industry:

Occupation Sector	Number of Women	Percentage
Sales and Office	443,000	74%
Professional & Management	236,000	13%
Natural Resources, Construction & Maintenance	122,000	2%
Service Occupations	14,000	20%
Transportation & Material Moving	13,000	3%

Numbers of Women in the Construction Industry Sector

2005	1,079,000
2006	1,131,000
2007	1,119,000
2008	1,069,000
2009	970,200
2010	807,000
2011	828,000

2011 General Construction Statistics

Total Workers in Construction	9,039,000
Men in Construction	8,211,000
Women in Construction	828,000

Source: Bureau of Labor Statistics — Current Population Survey at http://stats.bls.gov. This is an annual average based on monthly surveys of 60,000 households, equaling 150,000 people. Numbers are rounded off to the nearest thousands. Numbers printed on prior NAWIC Fact Sheets may vary due to changes in NAICS Sectors.

Table 2: 2011 NAWIC Fact Sheet

This statistic is surprising due to the fact that jobs in construction can offer higher wages for women than the “traditional” female career paths. The Bureau of Labor Statistics in 2009 compiled data to yield the following chart to illustrate that women represent an extremely small part of the industry and have a higher percent earing than men:

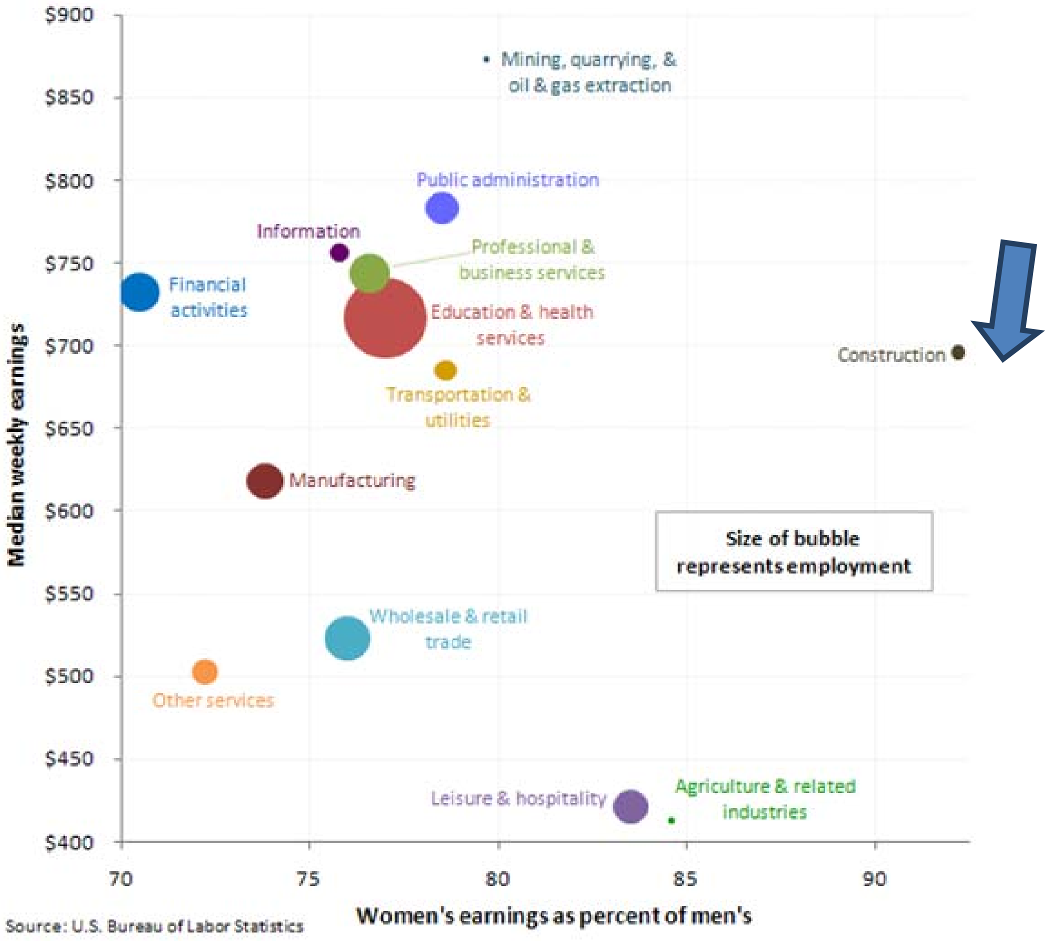

Figure 1: Employment and Median Usual Weekly Earnings of Women, by industry, 2009

As figure 1 shows, the construction industry for women is but a small speck on the chart of earnings for women. However the pay is within the top 50th percentile which is promising for women.

According to an article in Forbes by Jenna Grudreau, The Bureau of Labor Statistics (BLS) states that gender age gap is continuing to narrow. Across all fields in 2010, women earn 81 cents for every dollar earned by men which is an increase of 7% from 2000. Some young urban women are also reported to earn approximately 8% more than their male peers. This has been presumed to be due to higher college graduation rates in women.

An analysis in 2009 shows that the median weekly earnings for full-time workers, collected by the BLS, revels at least 15 jobs where women earn slightly more than their male colleagues. Among some of the most surprising jobs included construction laborers, construction supervisors, painters, and aircraft and vehicle mechanics.[5] This finding is extremely supportive of promoting women in construction trades and management roles.

Even though, the construction industry offers a wide range of challenging, satisfying, well-paid careers, over the last three decades, women have gained no ground in this industry. According to the Department of Labor's most recent statistics, in 2012, women represent only 2.3% of overall construction occupations.[6] In the United States, women comprise 14.6% of our active duty armed forces and have made substantial progress across many career fields. From 1981 to 2011, women moved from 4.4% to 20.7% of architects, 1.6% to 13.1% of civil engineers, 4.7% to 22.2% of dentists. However, the occupations in construction remained stagnant: 1.8% to 1.9% for carpenters, 1.6% to 1.5% for electricians, and 2.1% constant for construction laborers.[6]

The results of the research are expected to show a significant gap between genders in the construction industry. The results will also shed light on the reasons behind low female participation in the construction industry as a whole. The barriers females face such as non-equal pay, potential harassment, lack of information available about this career option, and the male dominated environment will be investigated in detail and explained. The final research conclusions are being tabulated, as this is an ongoing research project. The conclusions drawn from paper will provide a set of recommendations and guidelines to increase the participation of women in the US construction industry which will ultimately result in positive benefits to the overall economy.

6. RECOMENDATIONS

It is important for the United States workforce to collaborate to recruit and retain women in male dominated fields, especially construction management. Employers should simultaneously be educated about the benefits of diversifying their employee population.

In order to improve these numbers, the construction industry needs to make an effort to promote, inform, and educate women about the benefits of choosing this career path. Employers also need to be educated of the benefits of having women in the industry. The model below for women participation has been adapted from the 2007 article "Women in Construction Trades: A Strategic Plan to Promote Women"

Sector	Suggested Methods for Improving Participation
Hiring Employers	▪ Presentations about working in the construction industry Incorporate strong message marketing trades to girls ▪ Promote company as female friendly company which values equal opportunity. ▪ Set attainable numerical goals to improve gender ratio ▪ Highlight equal opportunity values when answering questionnaires for magazines or other marketing agents ▪ Inform those responsible for hiring to portray realistic pictures of trades and the construction management industry to women

Professional Development	▪ Make career development/ advancement opportunities available to women. ▪ Use a mentoring program for new hires ▪ Educate women on how to advance and promote themselves within the organization ▪ Try to increase female numbers to at least 15% ▪ Employ more women in leadership roles to can create motivation from within the company ▪ Offer more training programs and hands-on skill development for women
Elementary and High School Education	▪ Make young girls aware of opportunities for women in construction management as well as construction trades ▪ Break stereotypes by holding presentations and showing photos of women ▪ Encourage girls to take trade courses in ▪ Partner with Technical Schools and women construction organizations ▪ Launch a campaign to educate guidance consolers on women within the construction industry.
College and Educational Institution Sectors	▪ Address the situation of lack of females within the industry and lack of awareness. ▪ Identify sources of funding for women in construction trades and management ▪ Ensure there are continuous employment training programs and workshops for women about working in the construction industry. ▪ Career fairs and company promotion on campus should target females.

Table 3: Women Participation in Construction Model

The Women Participation in Construction Model suggests that in order to increase women population within the construction industry, four separate sectors must work together in order to break down the previously discussed barriers women face. The model suggests that women’s perspective of the construction industry begins at a basic elementary education level. If young girls become aware of opportunities for women in construction and are not biased because of the male dominated stereotype than when the time comes to pursue a career, these women will have fewer barriers to face. As women continue through their education, advisors and professional women organizations should promote the construction industry as an equal opportunity industry. Encouragement for funding and trade schools as an option for women should take place at this time. If hiring employers or the recruiting entity shows a positive and welcoming image for women, women will become more intrigued and comfortable with this industry as a career option. Once women are hired into the construction industry, the employer should take crucial measures to retain them. The retaining entity of this model must ensure that there are career advancement opportunities equally and clearly available for women. Offering hands-on training work-shops and mentoring programs can also increase retention.

7. CONCLUSION

The model proposed in this paper can be used increase the number of women in the construction industry benefiting not only female professionals but the industry as a whole. The increase in women is crucial for the growth and success of the construction industry. Actively pursuing a greater number of women within the industry can be simplified to a general model to obtain and retain females within the industry. The objective of this research was to develop a model which can be followed by women within the construction industry as well as industry leaders. This model gave guidelines for educational as well as professional entities to recruit, retain, and increase personal growth of women within the construction industry.

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INTERDISCIPLINARY, BIM-SUPPORTED PLANNING PROCESS

Lars Oberwinter

Vienna University of Technology, E234 - Institute of Interdisciplinary Construction Process Management, Vienna, Austria, Vienna, Austria, Oberwinter@industriebau.tuwien.ac.at

Iva Kovacic

Vienna University of Technology, E234 - Institute of Interdisciplinary Construction Process Management, Vienna, Austria, ikovacic@industriebau.tuwien.ac.at

Christoph Müller

Vienna University of Technology, E234 - Institute of Interdisciplinary Construction Process Management, Vienna, Austria, Vienna, Austria, cmueller@industriebau.tuwien.ac.at

Kristina Kiesel

Vienna University of Technology, E259 - Institute of Architectural Sciences, Vienna, Austria, kristina.kiesel@tuwien.ac.at

Linda Skoruppa

Vienna University of Technology, E259 - Institute of Architectural Sciences, Vienna, Austria, linda.skoruppa@tuwien.ac.at

Ardeshir Mahdavi

Vienna University of Technology, E259 - Institute of Architectural Sciences, Vienna, Austria, ardeshir.mahdavi@tuwien.ac.at

Abstract

Along with the rising technical capabilities of modern BIM applications, the performance requirements on interdisciplinary data and information exchange interfaces increase drastically. The planning practice reality demonstrates a number of problems with BIM implementation on technical (heterogeneous data, interfaces, large data volumes) but even more so on process level (question of responsibilities and work-load distribution, lacking standards or conventions on building-representation).

This paper will present the first results of an ongoing research carried out at Vienna University of Technology in cooperation with seven BIM software developers. The aim of the project is to evaluate the practical suitability of interdisciplinary data exchange interfaces and -methods offered by the current BIM tools and to point out preferable BIM software combinations at the current state of development to potential users. Also, insights are gained on an optimal way of modeling building elements within an interdisciplinary context.

Simulating a BIM supported planning process with students of architecture, structural engineering and building physics, the students were assigned to design a sustainable office building in interdisciplinary teamwork. Architectural, structural and ventilation models had to be created as well as an energy certificate and thermal and structural simulations. Each student group was assigned to work in a different, pre-defined software constellation and thus forced to handle interdisciplinary data exchange with the given interfaces. Thereby, data on technical issues (interoperability, usability) and process-related issues (efficiency, communication and coordination effort) were collected by the means of protocols and time-sheets.

Evaluating both, the primary BIM data and the according process documentation produced by the student groups, first findings show that an integrated, BIM-supported planning process in a heterogeneous software environment remains a big challenge due to interface limitations, regardless of which software constellation is chosen. Anyhow, first improvement solutions concerning both modeling conventions and technical interfaces have been identified.

Keywords: Open BIM, Collaboration, Integrated Planning, Exploratory Research, Experiment

1. INTRODUCTION

With upcoming requirements for sustainable buildings, the need for more integrated planning practice, which would enable simultaneous collaboration of various disciplines in order to share and create new common knowledge, arises. BIM is largely understood as object-oriented digital representation of a building or built environment that enables interoperability and data-exchange in digital form (Kiviniemi et al. 2008). In this context BIM addresses primarily the process of model-building and information exchange (Succar 2010). BIM (Building Information Modeling) has often been recognized by research and practice as a suitable tool to support collaborative planning and to facilitate communication and information exchange between participating planners. Eventually it can lead to higher efficiency and quality (Rizal and van Berlo 2010). BIM seems especially promising in terms of life-cycle oriented planning and optimization. Furthermore, time efforts can be reduced. BIM is believed to bear large potential towards integrated design (Prins and Owen 2010) inducing a shift from AEC (Architecture, Engineering, and Construction) fragmented practice that still largely dominates this industry (Fellows and Liu 2010). Rekkola et al. (2010) argue that “integrated design” is still handled rather loosely in the practice – often the creation of BIM model is sufficient for the project to be referred to as “integrated project”, regardless of actual interdisciplinary data sharing and model use. BIM, in our understanding, is much more about how (design process), than about what (building model and its properties).

Since the AEC industry is project-oriented, the small markets are characterized by high fluctuation of the employees and related know-how loss. Owen et al. (2010) point out the need for BIM related trainings to enhance skills of project members. So far, they are often highly specialized in their own fields of expertise, but seldom trained to work in integrated project environment. The organizations also support this kind of professional development rarely. In most cases, the introduction of new BIM-tools means more than simple CAD-tool shift. The adoption is mostly related to the reorganization of the processes and the project related management strategy.

In the practical BIM operation and use a number of problems on different levels can be met. On the technological level the question of interfaces in the data transfer of the interdisciplinary models arises. Additionally, one has to cope with the heterogeneous data-structures from different software, the art of model building, and the management of ever larger data-volumes. On the semantic level, it can be noticed that each discipline needs individual information; the professional languages differ strongly as well as the means and methods to represent a building (Bazjanac and Kiviniemi 2007). The spectrum reaches from diverse lists for project management and quantity surveys, reduced slab model for structural engineering to complete spatial representation of architectural model in the full geometric complexity.

Reliable management, filtering, and synchronization of this information in the context of still dominant heterogeneous software-structures, require high effort in organization, administration, interdisciplinary communication, and know-how. A standard solution offering the complete software package for this large spectrum does not yet exist, and it is a question whether such solutions are viable for every building as every design process is of prototypic nature.

The high fragmentation of the design and construction process disables the management of complexity. The linear planning process of highly specialized disciplines proves as not suitable in order to accomplish sustainable buildings. The necessity to change the way buildings are designed, constructed, and operated is being continually pointed out by the current practice. The emerging of highly developed BIM tools together with a paradigm shift from a linear, fragmented process towards a more integrated practice that would not only bring benefits for the planning and construction but even more so for the optimization of the operation of a building. A life-cycle oriented approach brings whole-life value, enabling knowledge management and -transfer from life-cycle phase to phase and integrating building services and automation systems (Owen et al. 2010).

The BIM research has mainly been focused on problem-solving of software-interoperability and efficient data exchange. Recently the academic community has realized that the successful BIM-adoption towards more integrated design and delivery is not related to the handling of technical issues only. Rather the design process itself needs to be organized (Succar 2010, Penttilä 2008). This relates to the internal organization and standardization of the workflows, role descriptions and related responsibilities of the stakeholders, as well as to the general commitment towards collaborative planning attitude. Rekkola et al. (2010) argue, that the lack of knowledge beyond technological issues, regarding workflow and business practices, is crucial. Within the case study, they identified problems and benefits of a BIM-supported integrated process and assigned them to the following categories: (1) people (competence or knowledge problem), (2) process (workflows, timing, contracts, roles), and (3) technology (software). Rekkola et al. (2010) argue that for enhanced integrative practice a participative process is necessary and that the slow BIM-adoption in the practice is caused by the difficulty of interrelation (triangulation) of the people-process-technology problems.

Therefore, the greatest challenge for holistic concepts, such as Building Life-cycle Management (BLCM) (von Both 2011) or Integrated Design and Delivery Solutions (IDDS), (Prins and Owen 2010) are the people and the process. An integrated, interdisciplinary building model requires close cooperation and coordination of the planners and contractors, the industry and the facility management, a highly skilled project team and detailed conventions on an inter-organizational level (Sacks et al 2010; Plume and Mitchell 2007; Arayici et al. 2011).

2. METHODOLOGY

In order to evaluate BIM-supported interdisciplinary planning, the use of BIM tools in an interdisciplinary context was tested in a design class. The experiment is part of an ongoing research project 'BIM-Sustain: Process Optimization for BIM-supported Sustainable Design'. This project involves three institutes of Vienna University of Technology and seven BIM-software developers. This interdisciplinary collaboration between university and industry enables the development of customized strategic concepts for the individual BIM-settings within multi-disciplinary planning environment. The aim of the project is the development of a framework for a BIM-supported planning process. This includes recommendations for data exchange, suggestions regarding the improvement of software interoperability, and recommendations for a BIM-supported design process.

An experiment within an interdisciplinary design class involving 40 students was set up. Therefore, the collaborative, multi-disciplinary BIM-supported planning process of designing an energy-efficient office building was simulated. The class was divided into 11 teams. Each team consisted of at least one architect (ARCH), one structural engineer (ENG) and one building physicist (BS). A survey on software experiences and preferences was conducted and different software combinations, as described in Table 1, were assembled. The teams were formed according to prior experiences and preferences regarding the software tools.

The software constellation shows different workflow models: One-Platform BIM (proprietary) and Open-Platform BIM using IFC 2x3 (Industry Foundation Class) interface.

Team	**Architectural Model**	**Structural Engineering Model**		**Building Science** (Simulation in TAS)	
	CAD	**CAD**	**FEM**	**CAD**	**Calculation**
1	Allplan	Allplan	Scia Engineer	Allplan	Allplan
2	Revit	Revit	Sofistik	Revit	Plancal
3	ArchiCAD	Tekla	Dlubal RFEM	Plancal	Plancal
4	ArchiCAD	Allplan	Dlubal RFEM	Plancal	Plancal
5	Revit	Allplan	Scia Engineer	Plancal	Plancal
6	ArchiCAD	Allplan	Dlubal RFEM	Revit	Plancal
7	Allplan	Tekla	Sofistik	Revit	Plancal
8	Revit	Tekla	Scia Engineer	Allplan	Allplan
9	ArchiCAD	Revit	Dlubal RFEM	Plancal	Plancal
12	ArchiCAD	Allplan, Tekla	Dlubal RFEM	Revit	Plancal
13	ArchiCAD	Tekla	Sofistik	Revit	Plancal

Table 1: Software constellation within the student groups – Open-Platform BIM

The Open-Platform BIM uses different software products and works with a central architectural building model. The data is exchanged via IFC. IFC is a standardized interface to describe a building model digitally (buildingsmart 2013). The One-Platform BIM works with one software family. In this experiment this applies to Nemetschek Allplan (2012) or Autodesk Revit (2012) which use proprietary standards.

The groups were given an assignment consisting of a functional program, site-plan with orientation and set origin, layer-structure and color scheme for room-stamps. Table 2 gives a short overview of this assignment.

Type	office
Gross area	7500 m²
Employees	300
Location	Vienna
Concept	low energy
Construction	Concrete
Heating demand	< 50 $kWh.m^{-2}.a^{-1}$

Table 2: BIM_sustain class assignment

The design class was scheduled for one semester and a timetable with deadlines was set. Apart from weekly crits, three presentations were scheduled for different phases. The first one focused on the architectural design. In the second presentation the structural and thermal solutions were discussed. The final presentation covered the optimized, full model including all information. Figure 1 describes the workflow and the discipline related tasks. By means of the mandatory protocols and time-sheets the technology related problems (data transfer inconsistencies or losses, semantics) and also to the process-people related problems (conflicts, communicational difficulties, lack of work-flow definitions or responsibilities etc.) were identified. Additionally an e-learning platform has been set up, with a forum for tutor feedback as well as for student-communication. This platform was also used for scheduling and posting of tasks.

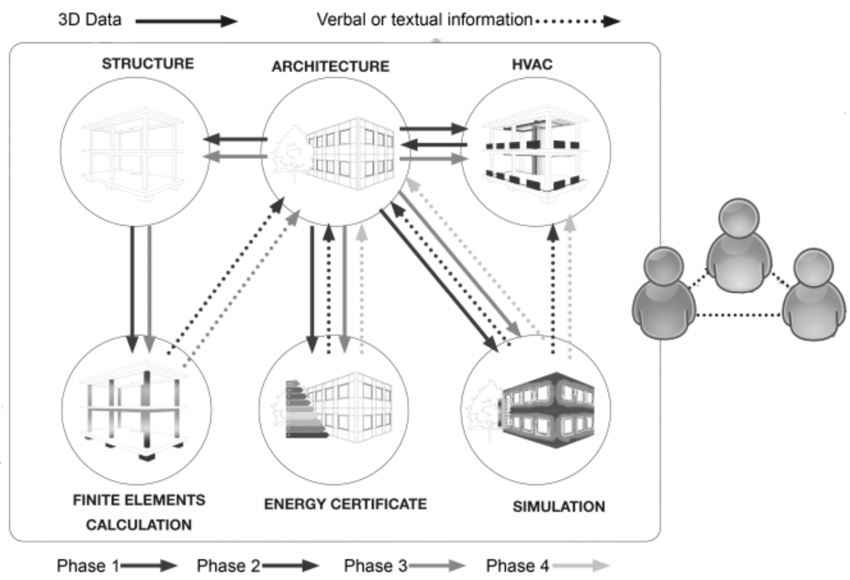

Figure 1: Discipline related Tasks and Models

The students had to protocol their work throughout the semester. These timesheets were then analyzed. In this way, information was gathered on workloads and time spent on specific tasks. The analysis of the protocols revealed the technology and communication related problems and challenges, as well as the applied solutions. In this paper we will present the qualitative analysis of the process, based on the protocols, using the so called fault tree analysis (FTA) for one of the participating teams (team 2). Team 2 is working in 'One-Platform-BIM' modus, using Autodesk Revit for both architectural and structural modeling. For the structural calculation Sofistik is used by the means of a plug-in imbedded in Revit.

3. FIRST FINDINGS

The architectural model was set up in Revit and exported with Revit Structure, a proprietary interface (Sofistik plug-in). The structural calculation was carried out in Sofistik. It is not possible to use an IFC interface to export from Revit to Sofistik. Figure 2 shows the fault tree analysis for architect and civil engineer.

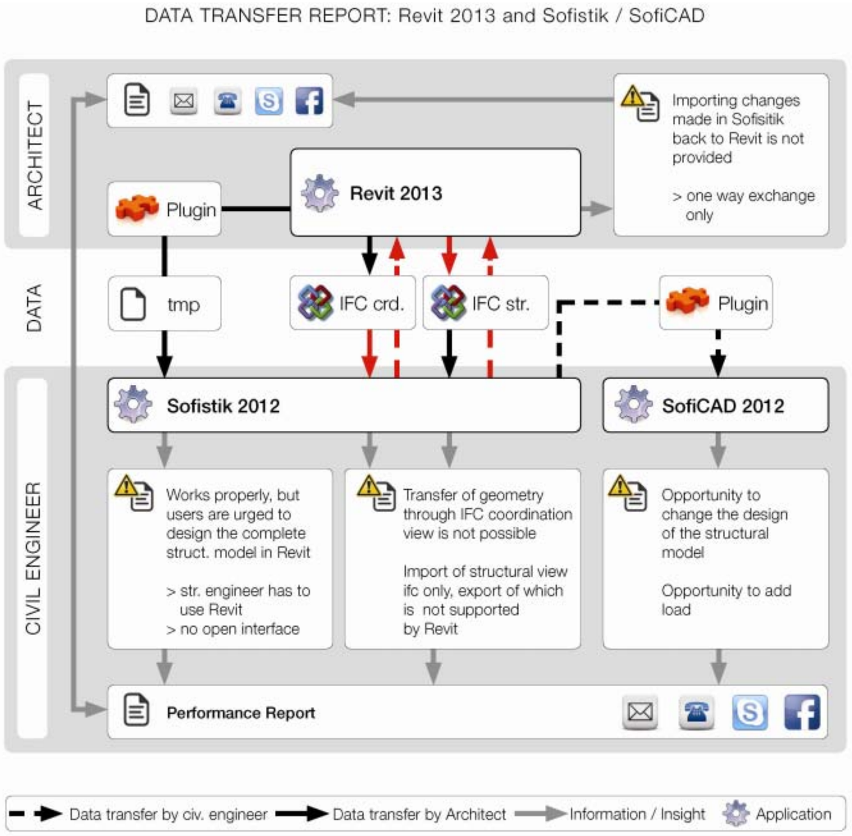

Figure 2: Fault tree analysis: architectural to structural model

The building physicist tested the architectural design for energy efficiency and thermal performance. To yield location specific results for Austria, special software with different interfaces had to be used. Figure 3 illustrates the data exchange between the architect and the building physicist. With the aim to report improvement suggestions of the construction concerning the thermal performance of the building, BS calculated an energy certificate, created a 3D model for thermal simulation, checked lighting possibilities, and planned a ventilation concept for the given model.

In team 2, BS received the architectural model as Revit file (.rvt) according to the software constellation. In order to generate the energy certificate for this building, an .aps file was required to import the information to the according software, in this case we used Archiphysik 10. Neither was Revit able to export an .aps file, nor was Archiphysik capable to import any other file format. Archicad was interposed with a special plugin to create an .aps file out of the .ifc file received from Revit. For thermal simulation we used EDSL Tas(EDSL Tas 2013) and for illumination scenarios Dialux (Dialux 2013). Both simulation programs accepted .gbxml format only. Green building markup language (gbxml) provides information about building elements and its characteristics in a structured hierarchical manner (xml.com 2013). Revit is capable to export this format as well. To draw the HVAC system, a plugin for Revit was necessary. This did not affect the workflow or data exchange.

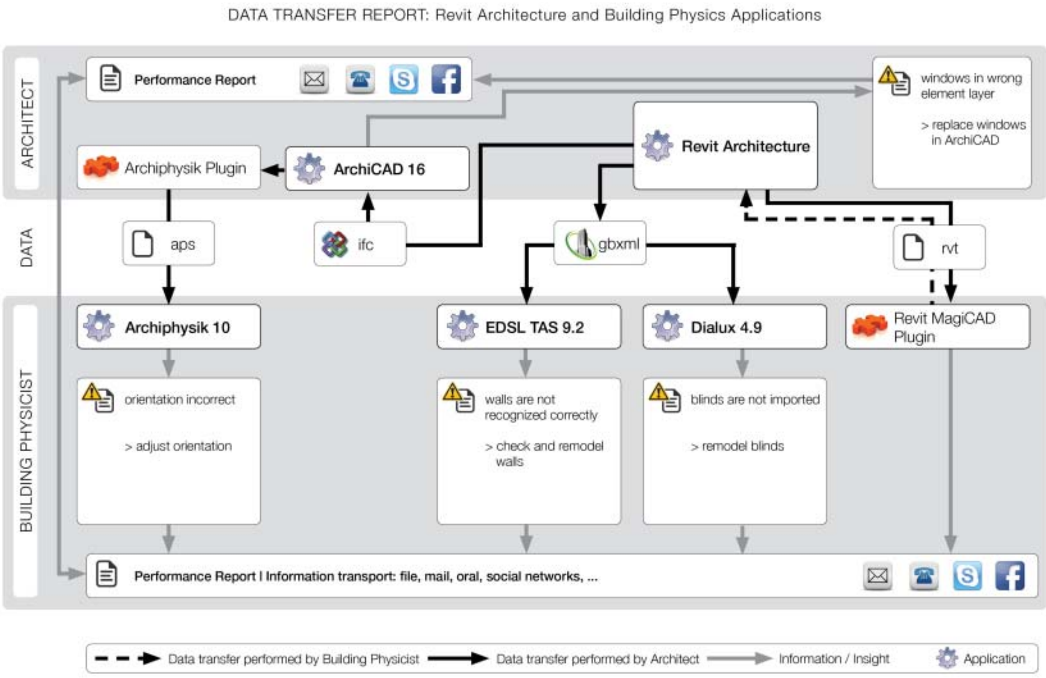

Figure 3: Fault tree analysis: architectural model to building physics software

After the files were imported into the simulation and calculation programs, incomplete data exchange and models were noticed by the building physicist. Consequently, adjustments had to be performed in order to receive the original model, e.g. correct the orientation, check and remodel walls and other missing elements.

In Archiphysik the orientation of the building was ignored by the program. This had to be corrected manually. EDSL Tas had problems recognizing building elements correctly. Especially walls had to be redrawn in most cases. In Dialux, shading devices were not imported and had to be added manually. Furthermore, no detailed information about the windows was transferred. Figure 3 illustrates the data exchange as well as the major problems with the data import.

The experiment showed that one of the main challenges is the preparation of the architectural model so it can be used for structural analysis and calculation. In the architectural model the wall construction line is commonly drawn on altering sides of a wall, the structural calculation requires the line to be centered in order to recognize the vertical connections and to be able to carry out the calculation. Without this knowledge it takes additional time to prepare and rework the model. The question arises whose task it is to prepare the model accordingly: the architect's or the engineer's?

After the calculation the structural model was adapted directly in Revit by the structural engineer, which was reported to be a complex task.

Shared problems reported by other groups are mostly related to the interpretation of geometry. The .ifc format but also the proprietary interface from architecture into FEM cause wrong geometry interpretation: recesses in wrong positions, missing walls, etc. Complex geometries such as round walls are also problematic.

A common problem was the incapability of ArchiCAD and Allplan to export structural-analysis-type ifc data, since FEM applications like Sofistik are only able to import this type (no ifc coordination view support).

CAD		FEM	
Archicad		Dlubal RFM	$\rightleftarrows$
Allplan		Scia Engineering	$\rightleftarrows$
Revit	$\rightleftarrows$	Sofistik	$\rightleftarrows$
Tekla	$\rightleftarrows$		

Table 3: Compatibility with IFC – Structural Analysis

It was observed that teams in that case applied the software which was not part of original matrix in order to enable export, a solution which could not be viable in the practice.

4. CONCLUSIONS

The case study has shown that a BIM-supported planning process requires thorough coordination and standardization in order to achieve its full benefits. Both, proprietary as well as open data exchange interfaces, face large problems in the interpretation of geometry, which often calls for complete rework of the architectural model in the discipline specific model. Some software combinations are even incompatible, which should be considered in the beginning of the planning to prevent high latter costs.

In addition, attempts to create building information models for full-on interdisciplinary use still face many contradictions concerning issues like wall construction lines (FEM vs. Building Physics), multi-story building elements such as columns, facades or elevators (ARCH vs. Tendering vs. FEM) and many more. It seems that currently, no matter how an architectural model is build up, it will cause problems in one or the other involved discipline – regardless of the used software environment and the creator's skill level. Besides from all technical issues concerning the data exchange interfaces, it seems that the agreement on how (and how detailed) a BIM model is to be created remains one of the most delicate issues for a successful integrated BIM supported planning process.

The fault tree analysis has shown that BIM as used in the experiment is still a one-way BIM. The way how the specific disciplines return the information in the basic model is quite different – with buildings physicists this can currently only be done by communication (report, mail, meeting); for the structural models this could in most cases be carried out digitally in the initial model. How the information should be fed back into the original model still remains unanswered, posting the question of rights to change the model and introducing the new planning profession such as BIM-manager.

BIM-based software-packages that fully support integrated, interdisciplinary planning practice and holistic life-cycle oriented data integration are still rather seldom. One-stop solutions for architecture and structural engineering, MEP (mechanical and electrical engineering), energy optimization, cost- and life cycle cost calculation are not available for the needs of central European planning practice and building policy. Due to different project-constellations and changing stakeholders with each new project, different combinations of software tools are to be met with each new project.

For a successful implementation of life-cycle oriented planning and management strategies, smooth data exchange without information losses are important. Therefore, further development regarding open data-exchange formats is required.

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FACTORS AFFECTING THE CURRENT DIFFUSION OF BIM: A QUALITATIVE STUDY OF ONLINE PROFESSIONAL NETWORK

Kriengsak Panuwatwanich
Griffith School of Engineering, Griffith University, Queensland, Australia, k.panuwatwanich@griffith.edu.au

Vachara Peansupap
Department of Civil Engineering, Chulalongkorn University, Bangkok, Thailand, vachara.p@chula.ac.th

Abstract

It has been widely recognised that Building Information Modelling (BIM) is one of the most critical innovations that represents a technological and procedural shift within the Architecture, Engineering and Construction (AEC) industry. BIM represents a methodology to manage the building design and project data in digital format throughout the building lifecycle. Although the benefits of BIM seem evident, its diffusion within the AEC industry has been slow and its current adoption has not been to its full capacity. To shed additional light on the diffusion of BIM, the research presented in this paper was aimed to examine and analyse the current perceptions of AEC professionals regarding their experience with BIM, which are publicly shared on a popular social network for professionals – *LinkedIn*. The research adopted Everett Roger's Diffusion of Innovation (DOI) theory as a conceptual framework to guide the analysis. The analysis was performed using a qualitative technique through *NVivo 10* software to analyse 45 discussion threads, retrieved from one of the BIM-specific discussion groups, for themes and concepts relevant to the diffusion of BIM. The findings revealed a number of key insights into the critical issues impacting the diffusion of BIM currently faced by the professionals within the AEC industry. These include: the difficulty for companies in adjusting their existing workflow and culture to accommodate the adoption of BIM in such a way that they can exploit its full benefits; the misconception of BIM that led to users' disappointment and eventual abandonment of BIM; and the implementation of BIM for short term gains rather than long term investment.

Keywords: BIM, Diffusion, LinkedIn, Nvivo, Qualitative

1. INTRODUCTION

The Architecture, Engineering and Construction (AEC) industry has long been characterised by its predominantly fragmented nature, which often results in the lack of efficiency, disputes and consistently lower-than-expected levels of productivity. Comprising over 10% of global gross domestic product (GDP), the AEC industry has the potential to shape the world economy; hence the need for it to be more innovative. A number of product and process innovations have been developed over the past decades in order to improve and propel the industry into a more desirable status.

One of the most notable advancement within the AEC industry is the development of the Building Information Modelling (BIM) concept, which is touted as a paradigm shift for the industry. Emerging in the late 1980's as reported by Björk (1989), the founding concept of BIM views a building component as an "object". Rather than being simply a geometric representation, this intelligent building object (referred to as "building product model" at the time) contains a set of properties including physical entities, geometric data, and appropriate relationships between building elements. A decade later, it was clear that such concept would practically revolutionalise how information is exchanged and transferred within the AEC industry. This subsequently gave rise to the better-known term BIM, which commonly refers to a methodology to manage the building design and project data in digital format throughout a building lifecycle (Succar, 2009). With the implementation of BIM, the design, construction and operation processes can be better streamlined to improve project efficiency. BIM is thus generally applied with the notion of decreased project costs, increased productivity and quality, and reduced project delivery time (Azhar, 2011). Although the benefits of BIM have been established and a number of BIM-capable tools made available on the market for many years, the diffusion of BIM within the AEC industry has been slow and its adoption has not been to its full potential (Becerik-Gerber and Rice, 2010; Linderoth, 2010).

In order to shed additional light on the diffusion of BIM, the research presented in this paper was aimed to examine and analyse the current perceptions of AEC professionals regarding their experience with BIM shared on a popular social network for professionals – *LinkedIn*. The research adopted Everett Roger's Diffusion of Innovation (DOI) theory to form the theoretical basis for the analysis. In the following section of this paper, relevant literature regarding the DOI and the diffusion of BIM is reviewed. The research method employed is then presented, followed by the results and discussion. The paper concludes with research implications and future research directions.

2. BACKGROUND LITERATURE

2.1. Diffusion of Innovations Theory

2.1.1. Overview

The DOI theory by Everett M. Rogers is one of the most widely cited references in many innovation studies. The theory provides a well-defined and systematic framework that helps explain critical elements and process of innovation diffusion. In Rogers' book, "Diffusion of Innovations" (first published in 1962), innovation is defined as an idea, practice, or object that is perceived as new by an individual or a unit of adoption. According to Rogers (2003), one reason why the diffusion of innovations has received so much interest is because "getting a new idea adopted, even when it has obvious advantage, is often very difficult" (p.1). Diffusion, as defined by Rogers, is "the process by which an innovation is communicated through certain channels over time among the members of a social system" (Rogers, 2003, p.5). For the purpose of this research, two aspects of Roger's DOI theory are presented: the elements of innovation diffusion and the attributes of innovations.

2.1.2. Elements of innovation diffusion

Innovation diffusion involves four key elements: (1) Innovations; (2) Communication Channels; (3) Time; and (4) Social System. These elements are essential and are identifiable in every diffusion research study as well as in every diffusion program. *Innovations* can be either creative ideas, which lead to the development of new or innovative products, or new technologies or practices adopted to improve either the production process or the product itself. *Communication channels* are the means by which the information (regarding innovations) is shared and exchanged among organisation members. *Time* is an important element in the diffusion process in the sense that it is used to determine the earliness/lateness and the rate of diffusion. *Social system* refers to a set of interrelated units that are engaged in joint problem solving to accomplish a common goal.

2.1.3. Attributes of innovations

Rogers also proposed five attributes of innovations which can affect the rate of adoption: Relative Advantage, Compatibility, Complexity, Trialability and Observability. He reported that these attributes are significant predictors explaining 49%-87% of the variance in the rate of adoption of innovations. These attributes are briefly described below (Rogers, 2003).

– *Relative Advantage* – this refers to the degree to which an innovation is perceived as being better than the idea it supersedes. This can be measured by such indicators as economic advantage, social prestige, convenience, and satisfaction. The greater the perceived relative advantage of an innovation, the higher the rate of adoption is likely to be.

– *Compatibility* – this refers to the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters. If an innovation is not compatible with an individual's needs, norms or practices, it will increase the level of uncertainty and the rate of adoption of the innovation will decrease.

– *Complexity* – this refers to the degree to which an innovation is perceived as relatively difficult to understand and use. Complexity is negatively correlated with the rate of adoption. That is, innovations that are less complicated and easy to use will be more likely to be adopted by individuals.

– *Trialability* – this refers to the degree to which an innovation may be experimented with on a limited basis. Innovation that is trialable can improve its rate of adoption because trialability tends to reduce uncertainty perceived by individuals.

– *Observability* – this last attribute refers to the degree to which the results of an innovation are visible to others. That is, the easier it is for individuals to see the results of an innovation, the more likely they are to adopt it.

2.2. The Diffusion of BIM within the AEC Industry

2.2.1. Perceived benefits of BIM and its current diffusion within the industry

Theoretically, BIM has the potential to promote greater efficiency as it encourages integration of the roles of all project stakeholders and business structures and practices into a collaborative process that enables the reduction of waste and optimisation of efficiency through all phases of the project life cycle (Azhar, 2011). Since the conceptualisation of BIM in the late 1980's, numerous studies have been carried out to ascertain the practical benefits of BIM within the AEC industry (e.g. Becerik-Gerber and Rice, 2010; McGraw-Hill, 2009, 2010). They identified such benefits as improved design quality, accurate drawing sets, reduced change orders, reduced field conflict issues through early clash detection, automated assembly and better production quality, improved productivity and efficiency, and perhaps most importantly, improved project profitability.

Consistent with Rogers' statement cited above, "getting a new idea adopted, even when it has obvious advantage, is often very difficult", the diffusion of BIM has been at a relatively slow rate given its far-reaching benefits and considerable presence within the industry for more than a decade. A study conducted by McGraw-Hill (2009) revealed that about half (49%) of the AEC industry in the US used BIM. A more recent study, also by McGraw-Hill (2010), found that in Europe the adoption rate of BIM was even lower at 36%.

2.2.2. Factors affecting the adoption of BIM

Due to the lower than expected rate of BIM uptake, the diffusion of BIM within the AEC industry has been a topic of interest by many researchers in order to understand the barriers and drivers of BIM adoption. For example, a survey by Tse et al. (2005) on the utilisation of BIM conducted in Hong Kong revealed the following reasons for not using BIM as reported by the research participants:

– BIM is not required by the clients and other project team members;
– Existing CAD systems are already adequate in fulfilling the design and drafting needs;
– Complicated and time-consuming modelling process;
– Inadequate BIM skills/training; and

– Extra file acquisition costs and the unavailability of free trial software.

In addition, the authors also identified a number of reasons that would drive the research participants to adopt BIM:

– BIM is required by clients;
– Other project team members decide to move to BIM;
– Adequate technical support and training are provided;
– Observable large productivity gain; and
– Downstream applications of BIM are in place.

A survey with 16 UK practitioners and academics carried out by Arayici et al. (2009) identified the primary barriers to BIM adoption as follows:

– Unfamiliarity with BIM use;
– Reluctance to initiate new workflows;
– Not enough opportunity for BIM implementation;
– Benefits from BIM implementation do not outweigh the costs to implement it; and
– Benefits are not tangible enough to warrant its use.

According to the above findings, the barriers appear to be mainly related to the attributes of BIM itself, while others are associated with the social system within which the research participants operated. According to Linderoth (2010), "the adoption and use of BIM will be shaped by the interplay between the technology's features and the context in which it would be adopted and used" (p.66). Therefore, the understanding of BIM diffusion requires an examination into the innovation attributes of BIM and their relationships with other organisational and business environment factors.

3. METHOD

3.1. Approach

In this research, a qualitative analysis of social media data was employed as an alternative approach to the traditional survey and case study methods. According to Highfield (2012), internet social media provide a communication platform that facilitates the development, sharing and exchanging of online conversations around topics of interest, where participation is not necessarily limited by geographical or social factors. Its ease of use, speed and reach enable social media to transform public discourse in society and set trends and agendas in topics ranging from the environment and politics to technology and the entertainment industry (Asur and Huberman, 2010). The sheer volume and variety of the information that propagates through large user communities presents a great opportunity for harnessing the data to study, analyse or predict a specific phenomenon (Asur and Huberman, 2010).

3.2. Data Collection

For the purpose of this research, the *LinkedIn* social network platform was chosen as the source for data collection due to its primary focus on professional networking. In particular, *LinkedIn* has a feature that allows members to create and join the discussion groups of their interests. A search on *LinkedIn* showed numerous discussion groups related specifically to BIM. This research, however, focused solely on the "BIM Experts" group, which is one of the largest BIM-related discussion groups on *LinkedIn*, consisting of 19,646 members (at the time of writing this paper). According to the group's statistics, the majority of the members are senior professionals in the fields of architecture and construction with locations in the UK and USA. The group has active discussions, generating more than a hundred posts and comments weekly. It thus provides an adequate source of data for examining a variety of issues related to BIM adoption and utilisation.

A qualitative analysis approach was employed in this research to analyse discussion threads retrieved from the BIM Experts group for themes and concepts relevant to the diffusion of BIM. To gather textual data of the discussion posts and comments from the group, a feature in the qualitative analysis software *NVivo 10*, *NCapture*, was utilised. By using *NCaptur*e, discussion threads can be downloaded directly from *LinkedIn* into the *NVivo* software. This feature, however, has a limitation in the number of discussions comments that the software can download. Hence, it is not possible to obtain all the posts and comments stored in the discussion group. For this reason, it was decided that only the discussion posts that are specifically related to BIM adoption and implementation, together with their associated comments, would be considered for the analysis. To achieve this, a search was conducted on the discussion group using two keywords, "adopt" and "implement", which resulted in about 400 discussion posts. Through manual scanning and culling, only 45 posts with topics clearly relevant to BIM diffusion and with considerable follow-up comments (at least 8-10 comments) were retained.

3.3. Data Analysis

As mentioned previously, *NVivo 10* was used to perform a qualitative analysis in order to uncover important issues relevant to the diffusion of BIM within the AEC industry. *NVivo* facilitates the collection and organisation of textual data, and can be used to help perform a text analysis through such functions as word queries and coding. To carry out the analysis, all the 45 selected posts and their associated comments were captured directly from *LinkedIn* website and imported to *NVivo* using the *NCapture* feature. Following this, a "Word Frequencies" query was run on the entire dataset. This type of query allows the user to identify the most repeated words. It can also be configured to exclude a set of "stop words", which refer to those words that are not significantly meaningful to the research being conducted. Because this current research was more interested in studying issues that are "critical", only the words in the top ten highest frequencies were examined to limit the amount of data needed to be analysed. For each of the words listed in the query result, *NVivo* also shows all the discussion posts that contain such word, together with the frequencies of the word mentioned in each post (i.e. coverage).

Following the word frequencies analysis, a “coding” exercise was performed to extract important concepts associated with BIM diffusion from the discussion posts. To do this, five discussion posts with highest percentage coverage from each of the top ten queried words were selected for coding. The innovation attributes presented in Section 2.1.3 provide the theoretical framework that was used as the seed concepts (or “nodes” in *NVivo* term) into which the discussions were coded.

4. RESULTS AND DISCUSSION

4.1 Demographic Information

As mentioned in the previous section, 45 discussion posts related to BIM adoption and implementation were included in the analysis. These posts in total generated 1,818 comments, with 355 members from 35 countries contributing to the discussions. The majority of the contributors were located in the USA (48%) and UK (20%). Others include the countries from Asia-Pacific (e.g. Australia, New Zealand, China and India), Europe (e.g. Italy, France and Finland), Middle East (UAE, Saudi Arabia, Lebanon and Palestine) and South America (Brazil and Chile). The majority of the contributors were employed as company managers/directors (34%), and others include such professions as architects (9%), BIM managers/coordinators (9%) and engineers (6%). They mainly operated within the Architecture and Planning (39%) and Construction (30%) industries.

4.2. Word Frequencies Query Results

A word frequencies query was run on all the selected posts and their associated comments. It should be noted that the query was set to include stem words (e.g. words used as nouns, verbs or adjectives) and exclude stop words such as construction, draw and design. Table 1 highlights the top ten highest frequencies words extracted from the query results. The results provide an initial clue that the issues being discussed would be around how the modelling using BIM software might be related to the change in work process and information management. This is clearly the case given BIM is a methodology implemented to manage the electronic data throughout an entire building lifecycle. In addition, it can be seen that these words appear to be associated with the characteristics of BIM itself (e.g. process, software, tools and costs). Of note is that *Autodesk Revit* (ranked 9th in Table 1) seems to be the BIM-supported software that was of a particular interest to the group members. This coincides with the findings from the studies by Arayici et al. (2009) and Becerik-Gerber and Rice (2010) that *Autodesk Revit* are the most widely used BIM authoring tool in the UK and USA.

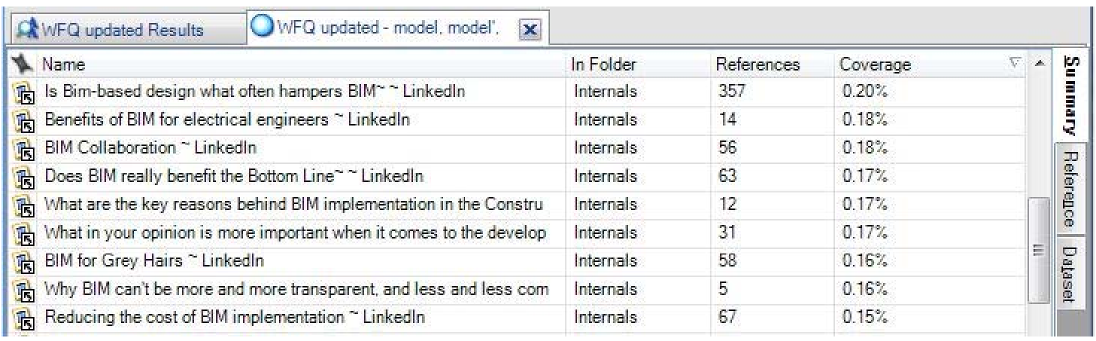
Rank	**Word (including stem words)**	**Count**	**Weighted %**
1	Model	1868	1.46
2	Process	1195	0.93
3	Software	909	0.71
4	Changing	678	0.53
5	Information	672	0.52
6	Management	648	0.50
7	Data	647	0.50
8	Tools	581	0.45
9	Revit	511	0.40
10	Costs	499	0.39

Table 1: Top ten highest frequencies words

As asserted by Linderoth (2010), the diffusion of BIM is affected by the interplay between its features and the context in which it is utilised. Although the above results provide some broad ideas on the current issues being discussed within the studied group, the contexts in which these words were mentioned required further examination and analysis in order to derive meaningful findings. This was achieved using the coding feature in *NVivo*. The coding results are presented in the next section.

4.3. Coding Results

For each of the top ten highest frequencies words listed in Table 1, five posts with highest coverage percentage associated with the word were selected for the coding. Figure 1 shows a screenshot example of the posts associated with the word "Model". For each post, the coding was carried out by examining the sections of texts containing the word of interest with the view to determine whether any sections of the texts can be associated with any particular concepts. These concepts (nodes) can be predetermined (*a priori*) or can be those that emerge after the coding process (*a posteriori*). For the purpose of this research, the set of predetermined concepts used as the reference for the coding was the innovation attributes presented in Section 2.1.3.



Name	In Folder	References	Coverage
Is Bim-based design what often hampers BIM~ ~ LinkedIn	Internals	357	0.20%
Benefits of BIM for electrical engineers ~ LinkedIn	Internals	14	0.18%
BIM Collaboration ~ LinkedIn	Internals	56	0.18%
Does BIM really benefit the Bottom Line~ ~ LinkedIn	Internals	63	0.17%
What are the key reasons behind BIM implementation in the Constru	Internals	12	0.17%
What in your opinion is more important when it comes to the develop	Internals	31	0.17%
BIM for Grey Hairs ~ LinkedIn	Internals	58	0.16%
Why BIM can't be more and more transparent, and less and less com	Internals	5	0.16%
Reducing the cost of BIM implementation ~ LinkedIn	Internals	67	0.15%

Figure 1: Screenshot of discussion posts containing the word "Model"

The summary of the coding results (ranked by number of references) is presented in Table 2. The table shows how many posts (sources) contained the sections of texts (references) that are relevant to each concept (node name). From the table, the relative advantage of BIM (49 references) and its compatibility with the current practices/processes (41) were most discussed by the group members. This is followed equally by the observable results of adopting BIM (33) and its complexity (32). Discussion on the trialability of BIM is the least extensive among the comments posted.

Node name	**Sources**	**References**
Relative advantage	17	49
Compatibility	14	41
Observability	15	33
Complexity	18	32
Trialability	6	11

Table 2: Summary of coding results

With respect to the “Relative Advantage” of BIM, the majority of members seemed to acknowledge that BIM helps in: improving collaboration, decision-making and speed of work; achieving more complete as-built information and greater certainty in design understanding, costs and schedules; eliminating burden on paper-based document control; minimising change orders; eliminating waste; lowering costs; and improving company’s competitiveness. However, some adoption barriers mentioned were related to the costs associated with software and hardware, training, and the change in existing workflow when implementing BIM. In addition, BIM is perceived to be not very useful in certain discipline due to its lack of capability to perform specific task.

The major barrier of BIM appears to be mainly associated with its “Compatibility” with existing workflow and business practices. Many commentators highlighted the difficulty at the industry level in changing the fragmented nature of construction business to a more integrated process in order to realise the benefit of BIM. This is similar at the company level where the transition to BIM-based practices was reported as the main barrier. Such difficulty was also linked to the misunderstanding of BIM concept that had led to the misalignment between BIM implementation and the company’s business objectives. It also had an effect on how clients perceive the value of BIM, which in turn impacted their decisions to adopt it.

In terms of the “Observability”, many members reported that they had achieved favourable results with the implementation of BIM. These include: the reduction in overall resource demands; improved ability to deliver more projects within the same time frame; ability to instigate positive cultural change in the company; procurement framework being more resilient to change; and improved transparency throughout the process. Some commentators even reported a rather more objective outcome including: up to 40% elimination of unbudgeted change; up to 80% reduction in time taken to prepare a cost estimate with accuracy within 3%; up to 10% saving of the contract value through clash detections; and up to 7% reduction in project time. On the other hand, there are members who also experienced unfavourable outcomes when adopting BIM. These outcomes include the significant drop in productivity during the transition to BIM, the value of BIM not evident to the clients, and little prospect of profitability.

The discussions on the "Complexity" aspect of BIM involved the views of BIM as both a piece of software and a process. While some members believed that the transition from CAD to BIM is not difficult, many reported that this involved a steep learning curve. The most difficult aspect of BIM implementation cited was the change to the existing work practices and the human resistance to adapt to it.

The comments relating to the last attribute, "Trialability", did not indicate any significant driver or barrier to BIM adoption. It was suggested that companies may experiment with only the modelling aspect of BIM (i.e. *Small BIM*) rather than to use it for the full lifecycle management of a building (i.e. *Full BIM* or *Big BIM*). By starting with the Small BIM, companies would have the opportunity to examine the benefits of BIM without putting too much of their bottom line at risk.

5. CONCLUDING REMARKS

The analysis of the discussions provided by the members of the "BIM Experts" discussion group on *LinkedIn* social network revealed a number of key insights into the current diffusion of BIM. Firstly, it was found that although many of the members acknowledged the benefits of BIM, the major barrier to its adoption is largely the difficulty in adjusting their existing work process and culture in such a way that they can exploit the full benefits of BIM. This is consistent with Arayici et al (2011) arguing that overcoming the resistance to change and adapting existing workflows to lean oriented (integrated project delivery) processes represent one of the major challenges in the implementation of BIM. Secondly, it was found that the misconception of BIM led to misinformed expectations regarding its benefits, and this resulted in the disappointment with BIM and its ensuing abandonment. The users who understood that the implementation of BIM would fundamentally affect the entire process of their business appeared to be more likely to appreciate the need for long-term investment in BIM to show positive returns. Hence, this group of users tended to be more satisfied with BIM and continued with the adoption. Meanwhile, those users who primarily focused on implementing BIM as a tool to gain short term benefits would be more likely to experience frustration and disappointment with BIM. Thirdly, while many group members reported positive outcomes as a result of BIM implementation, there is still a demand for solid evidence demonstrating that this is the case in the industry. Lastly, there are also a number of issues beyond the innovation attributes of BIM that affects its diffusion identified during the analysis. One of the most apparent issues is the need to foster the right culture and environment that allows the full benefits of BIM to be realised and appreciated. In past research, organisational culture and environment were found to be significant determinants of innovation diffusion (e.g. Panuwatwanich et al., 2008; Peansupap and Walker, 2005).

While the above findings shed additional light on the current diffusion of BIM, future work is required to further examine and address the issues uncovered in this present research. Clearly, it is worth examining the roles of culture at both the industry and organisational levels in facilitating the diffusion of BIM. The development of strategies is also required in order to assist the industry in gaining uniform understanding of BIM and managing the change during the adoption process.

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VISION-BASED APPROACH FOR MEASURING ON-ROAD TRUCK HEIGHTS

Man-Woo Park
Myongji University, Yongin, South Korea, mwpark@mju.ac.kr

Fei Dai
West Virginia University, Morgantown, WV, USA, fei.dai@mail.wvu.edu

Matthew J. Sandidge
AMEC, Atlanta, GA, USA, matthew.sandidge@amec.com

Ioannis Brilakis
University of Cambridge, Cambridge, UK, ib340@cam.ac.uk

Abstract

Crashes of trucks on overpass bridges and tunnels have been continuously reported in the United States over the years. The crashes inflict damages on the over-height trucks as well as the overpass itself. The damages involve direct costs related to injuries or fatalities for drivers or pedestrians and clearing/restoring the bridges and underway roads, as well as indirect costs charged due to traffic delays on both the overpass and the underpass. Smart systems that can automatically detect and warn oversize vehicles would help reduce these accidents, providing the vehicles with the opportunity to avoid a collision. As a type of smart systems, several technologies employing laser and infrared beams have been introduced. However, the high cost of implementing the systems constrains the wide use of those technologies. This paper proposes an alternative system to detect over-height vehicles in which one or two cameras replace expensive equipment required for the existing technologies. In the system, video streams are collected from a camera attached on the low clearance overpass, and processed to detect vehicles and measure their heights. The height measurement will be completed using line detection and blob tracking which locate upper and lower points of a truck in pixel coordinates. These 2D coordinates will then be translated into 3D world coordinates that will provide an approximation of the truck height. Preliminary experiments show 96.6% accuracy of measuring vehicle heights. The result signifies the potential of the proposed method to achieve a cost-effective warning system.

Keywords: accident avoidance, computer vision, height measurement, low clearance, over-height truck.

1. INTRODUCTION

Truck is a major transportation unit in the United States delivering nearly 70 percent of all freight tonnage (ATA 2007). It signifies the importance of unhindered flows of trucks across the nation. One of the areas where this evolves into a problem is during the transportation of freight on routes with low clearance overpasses. There are a considerable number of old low clearance bridges throughout the United States, which cause accidents associated with crashes of trucks on the bridges. In a study conducted by the University of Maryland where all states were polled and 29 states responded, 18 of those 29 or 62% stated they consider over-height collisions a serious problem (Fu et al. 2004). Even though the frequency of these accidents might not be thought significant, the costs they involve are considerably high. The damages involve direct costs related to injuries or fatalities for drivers or pedestrians and clearing/restoring the bridges and underway roads, as well as indirect costs charged due to traffic delays on both the overpass and the underpass. In order to avoid the accidents and to reduce involved costs, it is beneficial to have a warning system that detect an over-height truck and notify its driver ahead of the presence of the low clearance overpass.

A general preventive measure is to install signs along the road or on the overpass, informing drivers of the low clearance bridges. As a more active way, many states have started deploying warning systems using laser or infrared light (USDOT, 2011). The systems consist of 1) a transmitter and 2) a receiver mounted on opposite sides of the road, 3) loop detectors under the road, and 4) a visual/aural warning system (TRIGG industries, 2010). However, the high cost of implementing the systems (USDOT, 2008) constraints the wide use of those technologies. In addition, the installation of loop detector needs road blocks causing another indirect cost.

Vision-based system can be a cost-efficient alternative to the laser- or infrared-based systems. In the system, aforementioned three components 1)-4) can be replaced with one or more cameras and an embedded processor running computer vision algorithms. This paper introduces an overall framework of the system and proposes a novel method for measuring truck heights as a part of the framework. The method combines line segmentation and blob tracking in order to detect lines on the top and bottom of the truck. Two points are selected as they comprise a vertical line perpendicular to the road plane. The length of the line determines the truck height in 2D coordinates which can then be translated into 3D space. This process also involves unit conversions from pixel to a length unit such as meter or feet by use of a fixed reference object height.

2. BACKGROUND

The purpose of over-height vehicle detection systems is to detect the existence of an over-height vehicle on the roadway and be able to warn the driver of the vehicle of the pending danger before a collision with a structure occurs. The definition of an "over-height" vehicle is a vehicle that is too tall to successfully pass under an overpass. In the US, the allowed legal height of trucks is 13'-6", but permits are issued for the trucks over 13'-6" (GDOT 2012). It is still drivers' responsibility to confirm clearance heights along their routes. This regulation does not eradicate the problems. There still exist trucks violating the regulation as well as outdated low clearance overpasses. Accordingly, it is necessary to employ warning system which effectively informs drivers of the overpass clearance prior to them passing the overpass.

Warning system can be classified into three categories (Cawley 2002). The first category is passive system that uses static signing which shows the low clearance height well in advance. Although this system is inexpensive, its benefit/cost value was rated low because it relies highly on drivers' attention and can avoid only 10-20% of overpass crash accidents. The second category is sacrificial system. An audible alarm is made when over-height vehicles hit a physical obstruction such as chains, metal strips, or sacrificial beams installed at the overpass height in advance of the overpass. While chains and metal strips do not provide an alarm loud enough to be heard inside trucks, sacrificial beams cause damages on vehicles. The third category is active system which is called Early Warning Detection System (EWDS). In this system, the transmitter mounted on a pole at the height of the bridge clearance emits the laser or infrared beam. The interference of the beam due to the appearance of a truck activates a warning system that informs the driver with flashers and/or audible alarms. Loop detectors identify the appearance of a vehicle and their lanes (TRIGG industries 2010). The identification is used to remove false detections caused by non-vehicles such as birds. USDOT (2011) reported the decrease of accidents after the systems got in operation. The use of infrared light is more dominant than the laser in these systems, being considered safer and more durable in various environments than laser. However, the high cost of implementing the systems restricts the wide use of these technologies. For example, the deployment of the system on both bounds of a road in Maryland cost a total of $146,000.

As an alternative to the laser- or infrared-based system, vision-based system has been investigated (Khorramshahi et al. 2008; Shao et al. 2010). A vision-based EWDS is inexpensive since it can identify truck heights with only one or more cameras for each direction, which are equipped with a processor unit. Low cost will allow wide employment over the country. Once the cameras are positioned, their video streams are processed by an embedded processor unit to identify and locate vehicles. This processing involves three steps: camera calibration, vehicle detection, and vehicle tracking. Camera calibration provides a transformation between image pixel coordinates and real-world road-plane coordinates (Kanhere and Birchfield 2010). The transformation is necessary to obtain the width and height of a vehicle in metric units and to identify which lane the vehicle appears in. Vehicle detection recognizes a new vehicle entering the view, and the detected vehicles are tracked by a tracking method. In Khorramshahi et al.'s work (2008), feature points on a truck are located and tracked while the truck passes through a cubic virtual zone which is as high as clearance. Based on the relative positions of the tracked feature points and the virtual zone, it judges whether the truck height is over the clearance or not. However, creating the virtual zone which acts an important role in calibration requires manual marking. The marking should be executed based on the dimension of any vehicle that passes the zone. Therefore, it needs a priori knowledge about the vehicle dimension. In addition, this method is not able to calculate the exact height of the vehicles. Shao et al. (2010) proposed an automated method to identify the height of moving objects from un-calibrated videos. Despite its novelty, it is not applicable to general roadway scenes because two vehicles moving in two non-parallel directions should be present in the views for their automated calibration method.

This paper proposes an automatic, viable and inexpensive method to determine the height of trucks in digital video collected from a fixed camcorder. It should be noted that this research focuses on flat, single or double lane per direction roadways, daytime lighting, and one-directional flow for video processing.

4. METHODOLOGY

4.1. Methodology Overview

The overview of the vision-based EWDS is shown in Fig. 1. Video is obtained from a single camera mounted on a fixed position facing the roadway traffic and converted into image frames. The method then takes two parallel paths: field of view calibration and vehicle detection/tracking. The former reveals the principal axis and the Manhattan structure to establish field of view geometry, and the latter provides a bounding box of each truck. The results of the two paths are combined to calculate truck heights. The result is an estimate of a truck height, ready to be used in a EWDS.

4.2. Field of View Calibration

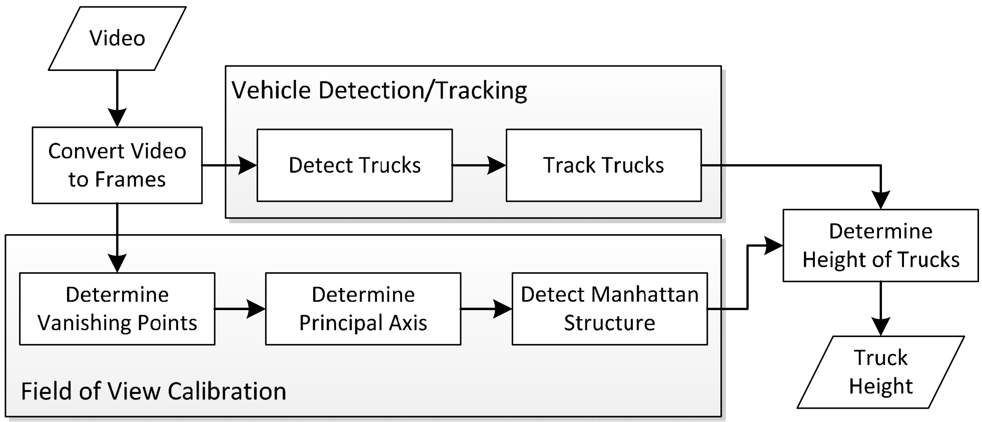


Figure 1: Overall framework of the over-height truck detection system

Once a camera view is fixed, three orthogonal axes comprising of the Manhattan structure (Coughlan and Yuille 1999) in real world coordinate system have to be found. The three axes consist of the principal axis along the direction of the road (or the traffic flow) (x-axis), a vertical axis perpendicular to the road plane (z-axis), and the other orthogonal to the formers (y-axis). The orthogonal axes are defined by three vanishing points. The following describes the way to find the axes. First, all line segments in the camera view are detected using the Line Segment Detector (LSD) (von Gioi et al. 2010). The detected line segments are then grouped as they converge to the same vanishing points. Accordingly, a number of line segment sets and their corresponding vanishing points will be generated. In Fig. 2, the line segment sets are illustrated in different colors. It can be easily seen that the blue lines form the majority and will make up a principal axis. Then, a set of line segments that are orthogonal to this principal axis can be found by examining a triplet of line segment sets and checking their orthogonality. The most orthogonal triplet of line segments makes up the Manhattan structure (Fig. 3). It is worthwhile to note that all processes are fully automated.

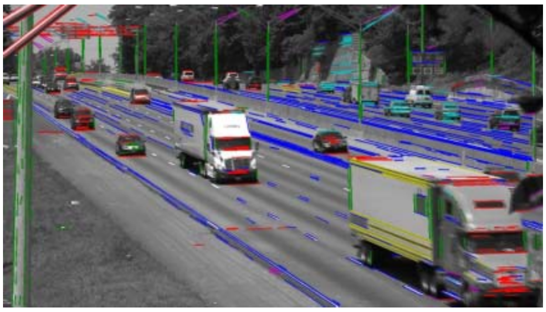


Figure 2: Line segment detection

Figure 3: Manhattan structure

4.3. Truck Detection and Tracking

In order to calculate truck heights, truck regions in video frames have to be located. Truck detection and tracking algorithms are used for this purpose. HaarCascade features (Viola and Jones 2001) which have proved to work well for vehicle detection are used for truck detection. Once a truck is detected, it is tracked in the subsequent frames by a separate tracking algorithm. The tracking algorithm employed in this paper uses eigen-images and particle filtering as an appearance model and a dynamic model (Ross et al. 2008). The output is a bounding box enclosing the truck.

4.4. Truck Height Determination

This section deals with a new algorithm for calculating truck heights. This algorithm is applied to the regions of bounding boxes obtained by truck detection and tracking. The linear workflow of the algorithm is shown in Fig. 4. First, a line segment corresponding to the top

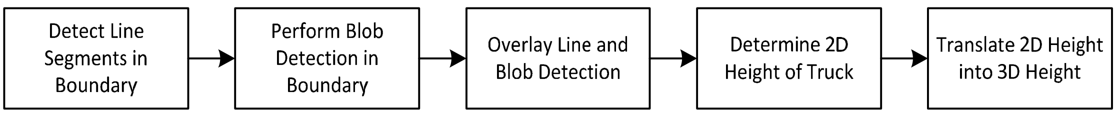
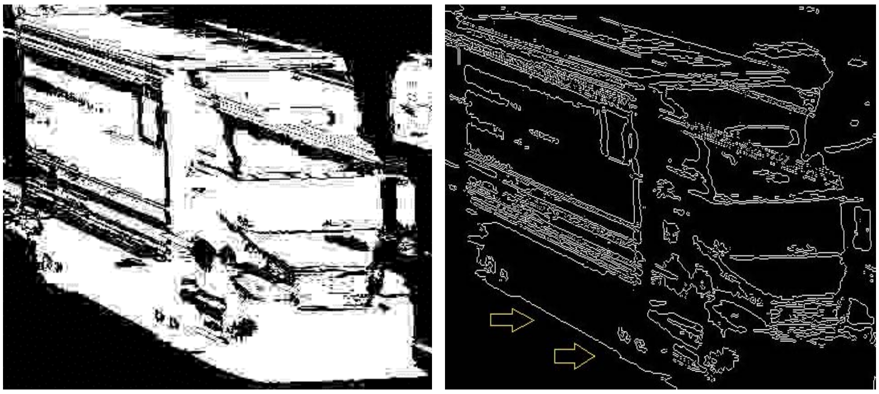


Figure 4: Height determination workflow

(a) (b)

Figure 5: (a) Line segment detection, (b) the upper boundary



(a) (b)

Figure 6: (a) Blob detection, (b) the lower boundary

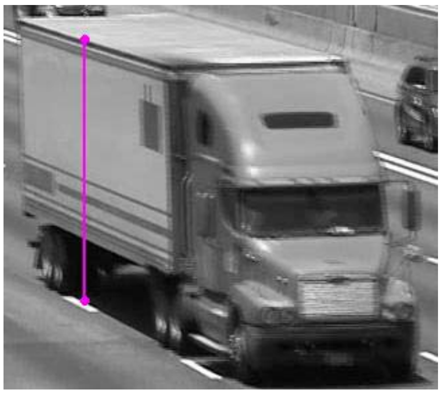


Figure 7: Truck height

boundary of a truck is obtained. All line segments inside a bounding box are detected by LSD method (Fig. 5a), and those whose direction is along the principal axis are selected. From them, the one whose left end point is closest to the top left corner of the bounding box is determined as a top boundary of the truck (Fig. 5b). Second, the truck's bottom boundary is located by using blob detection (Cheung and Kamath 2004; Li et al. 2003; Stauffer and Grimson 2000). The blob detection creates/updates a background model of static background scene and detects the regions of moving objects by comparing incoming video frames with the background model. The detected regions are called blobs (Fig. 6a). The boundaries of the blobs are extracted by applying the Canny edge detection (Canny 1986) to the blob image (Fig. 6b). The boundary indicated by the yellow arrows in Fig. 6b corresponds to the bottom of the truck.

The subsequent step is to measure the truck height in pixel units. The height is measured by locating two points – one on the top boundary and the other on the bottom – that forms a vertical line (in z-axis direction). It should be noted that the top boundary in Fig. 5b is a straight line in the same direction of the principal axis while the bottom one in Fig. 6b is winding. Hence, any point on the top boundary can be considered as a reference point. The remaining task is to find the correct part that lies on the actual bottom line corresponds to the top boundary. The following details the procedure of this task. The top boundary line is divided into n fragments by same length, which locates ($n+1$) points on the line. From each point, line scanning in z-direction is executed to search for the intersection with the bottom boundary. In this way, n sub-segments of the bottom boundary are obtained. From the sub-segments, one whose inclination is the closest (or the most parallel) to the top boundary line in the real world coordinate system is selected as the correct part of the bottom line. The height in pixel units is measured simply by calculating the distance between an end point of the selected sub-segment on the bottom and the corresponding point on the top boundary line (Fig. 7).

The final step is to convert 2D truck height in pixel units into 3D height in real world length units so as to compare with the overpass clearance. Single view metrology (Criminisi et al. 2000) is employed in this process. It takes known dimensions of objects in the camera view as input data. The road width and the length of the lane line pattern are good reference dimensions in y and x directions of the Manhattan structure, respectively. Based on the reference dimensions, the 2D height calculated in the image frames can be converted to a height value in real world units.

5. IMPLEMENTATION AND RESULTS

5.1. Implementation

A prototype was implemented to test the proposed method, which was built upon a platform named "Gygax". This platform has been developed using Emgu CV and Microsoft C#. Videos were collected using a Canon VIXIA HF S100 camera. The videos were recorded at a low clearance bridge over the Northside Drive in Atlanta, GA prior to the intersection of 17^{th} street. The videos were recorded in an "mts" format. This format is converted into an "avi" format from which "Gygax" can extract image frames in various formats such as "jpg" and "png". The original videos were recorded in 1280x720p resolution in color at the rate of 30 fps. During the process of video processing they were converted to gray scale images as required.

Three methods of blob detection were implemented to find the best option for this specific case of detecting the bottom region of trucks. The methods are the median filter method

(Cheung and Kamath 2004), the mixture of Gaussian method (Stauffer and Grimson 2000), and color co-occurrence method (Li et al. 2003). The results of this experiment are shown in Fig. 7. The median filter method is selected as the most appropriate since it provides the most dense region detection on the bottom of trucks. The density was measured by GIMP (GNU Image Manipulation Program). The median filter method generated 37.4% white pixels, while the mixture of Gaussian method and color co-occurrence method generated 32.6% and 16.5% white pixels, respectively.

The process of over-height detection was implemented and tested on four acquired videos, which are 6-8 minutes in length. Three parameters – (1) accuracy of height measurements in 2D pixel coordinates, (2) accuracy of height measurements in 3D real world coordinates, and (3) detection error rate – are considered to evaluate the performance of the proposed methodology. The parameters (1) and (2) are measured by comparing with actual ground truth data. The ground truth data for the parameter (1) is obtained by manual measurement. However, the ground truth data for the parameter (2), the actual height of a truck traveling on the road, is unknown. Therefore, a sample set of trucks with known heights was taken from the videos and tested separately for this purpose. Tested trucks are categorized into two classes – semi-trucks with standard trailers and box trucks. Total 60 trucks, 30 for each category, were tested to measure the performance of the proposed method.

5.2. Results and Discussion

The measurements of the three metric parameters are statistically analyzed, which are summarized in Table 1. Table 1 indicates the overall effectiveness of the proposed method. The heights 58 trucks out of 60 were successfully measured. The detected 2D image height when compared to the actual 2D image height boasts a 97.52% accuracy rate for the 58 measured trucks. This accuracy rate for estimated 3D truck height when compared to the actual 3D truck height drops slightly to 96.59%. This lower accuracy rate can be attributed to the inaccuracy of the vanishing line and point detection. There were two instances of failure in measuring truck heights, which results in 3.3% of detection error rate.

The average accuracy record around 97% signifies that the proposed method is highly accurate in measuring the height of trucks from streaming videos. The fact that it missed two trucks out of 60 calls for fine-tuning or enhancement so that it can be used in practice as part of a reliable warning system. This method is developed for low-clearance roadways, and uses cameras installed on the overpass. Depending on the road geometry and camera angles, trucks may be occluded in the view. To avoid the occlusion cases, it is recommended to use one camera per two lanes. One drawback of over-height detection using digital video is the fact that it is not applicable during night time because low light conditions. Further studies are needed to determine required levels of brightness and proper types of cameras for night time applications. Also, the impact of vehicle shadow on the performance of height detection at pixel level will be meticulously investigated.

# of Trucks		Accuracy of height in 2D pixel coordinates		Accuracy of height in 3D real world coordinates		Error rate of detection
Appeared	Measured	Mean	Standard Deviation	Mean	Standard Deviation	
60	58	97.52%	5.45%	96.59%	4.75%	3.3%

Table 1: Experimental Result Summary

6. CONCLUSIONS

Collisions of trucks on overpasses occur repeatedly across the US. The accidents pose a significant amount of losses including direct costs associated with vehicles and infrastructures and indirect costs caused by blocking the road. EDWS' will help reduce the collisions and unnecessary costs. This paper presented a vision-based EDWS which can be a cost-efficient alternative to the laser- or infrared-based systems. The system is comprised of four main processes – field of view calibration, detection/tracking, truck height measurement, and warning notice. Having the same warning system as the laser- or infrared-based systems, it can substitute cameras and embedded processor units for expensive equipment and infrastructure such as mounted poles, transmitters, receivers, and detect loops. As a part of the vision-based EDWS, this paper proposed a novel method to measure truck heights using a camera installed on an overpass. Given the detected region of a truck, the method locates top and bottom boundaries of the truck by using line detection and blob detection, respectively. The height is determined by measuring the distance between the boundaries and converting it to the real world length units. The method is implemented in C#, and tested on videos taken at a local road in Atlanta. In the experimental tests, the method achieved an accuracy rate of 96.59% in determining the truck heights in 3D real world coordinates. The merit of this research was the creation of an automatic image based method which can provide height determination of trucks and is a low cost alternative to the current expensive laser and infrared detection systems. Given the demonstrated capabilities, future efforts will detail cost comparisons and potential savings between the proposed video based approach and other height detection systems, in various operating environments. This proposed method could be the valid option for the budget limited DOTs that needs state-wide implementation of EWDS.

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MODELS OF ARRANGEMENT OF FINAL MATERIAL DEPOTS AT A CONSTRUCTION SITE FOR LABORS AND FOR ROBOTS

Attila Pém
Budapest University of Technology and Economics, Faculty of Architecture, Hungary, apem@ekt.bme.hu

Levente Mályusz PhD
Budapest University of Technology and Economics, Faculty of Architecture, Hungary, lmalyusz@ekt.bme.hu

Abstract

In this paper two models are introduced for optimizing the material depots arrangement at a construction site that serve a convex shape structure which 2D extension on the XY plane is substantially larger than its third extension (Z). The target is to minimize the construction time, cost or resources requirement by minimizing the sums of delivery distances from the final material depots to each point of the structure. In this model the feasible places of the final depots and the structures are used in a continuous way.

The usability and the farther generalization of the model are declared. It can be a tool for the construction site layout planning if the number of the units that build up the structure is large or unknown.

Keywords: facility location allocation problem, construction site layout planning, continuous demand

1. INTRODUCTION

One of the preventive works of a construction is the planning of the construction process. A partial task of the construction planning process is the *construction site layout planning (CSLP)* where space was recognized as a resource beside the time, material, labor, money and equipment [1]. The space types were clustered into five groups like: total space, product space, installation space, available space and required space [2]. Researchers have developed several models for CSLP.

Due to the number of the factors are involved into the CSLP, computers were identified as an efficient tool to solve the problem as computer-aided systems that are CAD-based [4], AI technique used [1] or genetic algorithm used [5, 6, 7, 8, 9, 10].

Most of the developed models identify the number and the size of the temporary facilities that serve the construction site then search for the optimal arrangement by minimizing the total transportation costs between the facilities or from facility to the structure that is required to be built:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} d_{ij} R_{ij}$$

where $\boldsymbol{n}$ is the total number of construction objects; $\boldsymbol{m}$ is the total number of constraining objects; $\boldsymbol{d_{ij}}$ is the travelling distance from the location of the construction object $\boldsymbol{i}$ to its ideal location concerning the constraining object $\boldsymbol{j}$; $\boldsymbol{R_{ij}}$ $\boldsymbol{(R_{ij} \in Q)}$ is the parameter that represents transportation cost or the weight of constraint between construction objects i and constraining object j [4]. The travelling distances can be calculated by using either Euclidean distance or rectilinear distance.

According to [11] there are two basic methods to deal with CSLP problem. One is placing everything to everywhere (or in a couple of combinations) and picking the best from these. The other that will be used in this paper is bringing objects in one type at a time in a certain order and calculating the optimal arrangement after each step [8].

A partial task of the CSLP is the *construction site elements allocation (CSEA)*. The site layout elements were clustered into three groups of objects: *site objects; construction objects; constrain objects* [12].

During the planning phase of a construction the construction managers use the architect's and engineers' documentation. The architects and the engineers define most of the structures as 3D CAD elements and represent them by 2D marking with Z directional information on drawings. Some of the structures are marked by pieces (for example pillars or windows), some of them are marked by line segments (for example wall tilling) and some of them are marked by areas (for example floor tilling, the concrete slabs or the boarding of the formwork of the slabs).

In this paper two models are introduced for optimizing the allocation of one kind of a construction object. It is the optimizing of the material depots arrangement at a construction site for those kind of structures that are modeled as areas in the engineers' documentation.

The base of the material depots arrangement is known as k-median problem in the operation research literature as a part of the *location allocation problem (LAP)*. Most of the LAP literature is based on discrete demand [2] like the known models of the CSLP where the target is to define the site objects' space and shape by a collection of unit areas.

In this paper models leave out of consideration the number of the delivery paths and the cost of the delivery from the truck and from the storage to the final depots because it is significantly less and negligible comparing to the number and the cost of the handling from the final depots to the structure. In this case the problem leads to the allocation problem where only just the length of the delivery paths counts. The models deal with one type of material at a time. The target is to minimize the length of the total handling path.

$$\min_{(a_i, b_i)} \sum_{1}^{k} \int\int (d) dxdy$$

where ***k*** is the number of the final depot; **P(*a$_i$*;*b$_i$*)** is the (x;y) coordinates of the i^{th} final depot; ***d*** is the Euclidean handling distance from the P(a_i,b_i) to each point of the structure.

2. CORROBORATION OF THE NECESSITY OF THE CSEA

In 2008 a survey was done in Budapest, Hungary where the needed handling time for the erection of the formwork of the first floor concrete slab was measured at a construction site *(Figure 1).* During the construction process the boards of the slab were band together as well as the beams were. These banded materials were lifted up in groups onto the already erected formwork parts by a tower crane *(Figure 2.)*. These groups of the materials are called as final material depots. Each final material depot of the boards contained 60 pieces of boards. After one group is positioned onto the erected formwork part the bind up rope was cut then the beams and the boards were delivered to their final positions one at a time by pairs of labors *(Figure 3.).*

Figure 1.

Figure 2.

Figure 3.

Most of the groups of the boards were not well positioned so the repositioning of the groups were needed. These repositioning were done by pairs of the labors too. The repositioning of the final material depots is an unnecessary work. It is waste of time, energy and money.

3. THE BASE OF THE MODELS

In this paper we present models that can be used to find the optimal final depots' arrangement that uses the structures as continuous demand as areas as the architects and engineers represented in their CAD drawings. The optimal arrangement can be searched on the entire XY plane. The optimal arrangement means the minimal of the length of the total handling paths.

The "length of the total handling path" from a certain point to all points of the structure is counted by the measure of segments, areas or volumes that are defined by the structure's representation as 2D marking $A_i(x,y,z)$ and the vertical projection of the marking $_{Ai'}(x,y,z)$ to the envelope of the Euclidean cone.

In the case the structure is marked by area the total delivery path from a *P* point to the structure is counted as a volume (area integral) as shown on *(Figure 4.).*

$$V_k = \int_{f^d(y)}^{f^u(y)} \int_{x=\min A_i}^{x=\max A_i} \left(|a-x|^2 + |b-y|^2\right)^{1/2} dxdy$$

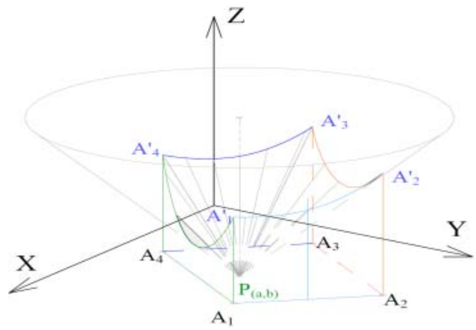


Figure 4.

where $(A_j A_{(j+1)} \ldots A_{(j+m)})$ (j=1…m, $m \in N$) is the end points of the line-segments of the perimeter of the area; $f_{(j;j+1)}$ is the curves of the perimeter of the area; $f^d_{(j;j+1)}$ is the lower curves of the perimeter of the area compared to the *X* axis; $f^u_{(j;j+1)}$ is the upper curves of the perimeter of the area compared to the *X* axis;***P(a,b)*** point is the projection of the center of the depot onto the *XY* plane and the center of the Euclidean cone; V_k is the area integral (volume) of the area, the projection of the area onto the envelope of the cone and the vertical boarding.

We declare that the volume that belongs to an area is proportional to the length of the perimeter of the area so the perimeter of the area is proportional to the length of the sum of handling path that belong to the certain area.

The final material depots will be represented by the projections of their center of gravity $P_k(a,b)$ to the ***XY*** plane. Each type of material has unique volume depots (for example a banded group of formwork boards). The number of the needed depot ***k*** can be calculated from the volume of the structure V_s or $Area_s$ that is given in advance in the CAD drawing and from the volume of a depot V_d or $Area_d$ that is also known in advance.

$$k = \frac{V_s}{V_d} = \frac{Area_s}{Area_d}$$

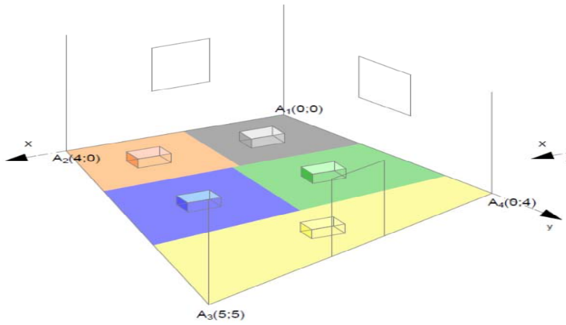
In the case *k=1* the solution can be found by any kind of 2 parameter minimization but if *k>1* it has infinite number of solution to partition the area of the structure into k pieces of V_k

volume (it means equal size) area. The target is to find the way of cutting the area that results the optimal or at least near optimal solution for CSEA.

4. DIFFERENT TECHNOLOGIES NEED DIFFERENT MODELS

There are two main differences in technologies that effect the allocation of the final depots. One (a) is the feasible area of the depots the other is (b) the permissible complicacy of the eventuated solution:

a) There are technologies when the final depot can be placed into the area that is served from the certain depot *(Figure 5a.)* and there are technologies when the final depot must be placed out of the served area *(Figure 5b)*. In the case when the final depots must not be placed into the served area the allocation of the final depots will affect the heading direction of the technology or the heading direction should be given in advance and then the heading direction will affect the arrangement of the final depots.



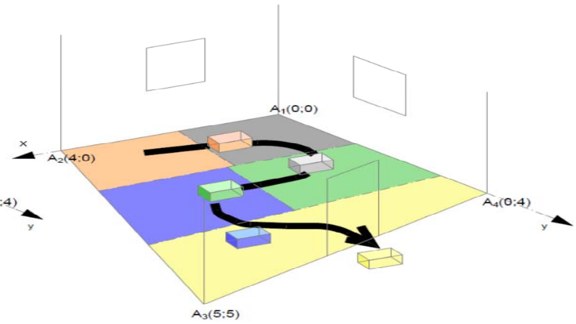


Figure 5a. *Figure 5b.*

b) If the eventuated solution is complex and complicated then the labors probably will make mistakes and will not serve only that area that should be served from the certain depot. It will possibly result an extremely worse solution compared to the optimal solution so this model should be used for robot technologies, when a robot does the handling of the materials.

5. MODELS IF THE FEASIBLE PLACES OF THE FINAL MATERIAL DEPOTS CAN BE PLACED INSIDE THE AREAS

For example during the earthwork the depot of the lumpy grave can be placed inside the area where from the grave has to be covered all-around the area. It can be used in every technology where it is not forbidden to place the depot inside the served area.

The target is to find the way of cutting the area that results the optimal or at least near optimal solution for CSEA. We declared that the length of the perimeter of an area that belongs to a depot is proportional to the length of the sum of handling path that belong to the certain area. This way we need to search for the way of partitioning the area of the structure into *k* pieces of equal areas that have the minimal length of the sum of perimeters.

$$\min \sum_{1}^{i} K_i$$

a) Model for robots, when no matter how complicated the result is and the location of the final material depots should be placed inside of the served areas

We use the well-known method named *Voronoi regions* for finding the best partitioning of the area of the structure. In mathematics a Voronoi diagram is a way of dividing an area into a number of regions. A set of points (called seeds) is specified beforehand and for each seed there will be a corresponding region consisting of all points closer to that seed than to any other. The regions are called Verona cells. [13] We need to find the allocation of the seeds that belongs to the Voronoi cells that have the minimal perimeter and have equal size of areas.

We invoked the software called *Mathematica 7.* to find the solution. Voronoi cells, the perimeter of the Voronoi cells and the areas of the cells can be calculated if all (*k* pieces) seeds are defined. If we randomly set up the allocation of the seeds inside the structure's area, then the area of the Voronoi cells will unintentionally be equal size areas.

If we set up a grid inside the structure's area where each node of the grid is a feasible place of a final depot *(Figure 6a.)* then the number of the solutions is the number of all permutations containing exactly k elements. It would unintentionally give the optimal solution based on the grid but the best solution *(Figure 6b.)* can be used for further iteration by setting a smaller grid around the best counted nodes *(Figure 6c.)*.

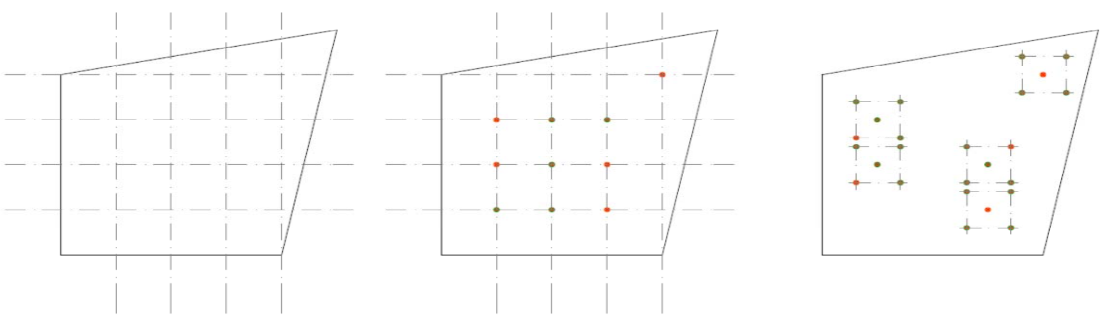


Figure 6a. *b.* *c.*

where the dashed line is the settled grid; the green points are the counted nodes; the red points are the counted best allocation of the seeds in the certain iteration.

The best counted nodes are where the *Precisness* has the highest value.

$$\text{Preciseness} = \max\left(\frac{\left(\frac{\text{Min}[\text{areas}]}{\text{Max}[\text{areas}]}\right)}{\text{K}}\right)$$

where ***Max[areas]*** is the maximum area of the cells' areas, ***Min[areas]*** is the minimum area of the cells' areas***, K*** is the sum of the perimeter of the cells.

This model is very similar to the *Neuman, T. and Wagon, S.* Wolfram Mathematica Demonstration [14] but in their model the hosts does not have equal capacity instead of the final material depots of a kind of construction material so the areas of the cells do not need to be equal.

A simple example

The area of the structure is given by the endpoints of line-segments: (A1(x,y)=(0;0), A2(x,y)=(4;0), A2(x,y)=(5;5), Ay(x,y)=(0;4)). The number of the final depots is known as well (k=5). The target is to find the optimal arrangement of the 5 final depots.

In the first step 10 nodes were set from the grid inside the structure as feasible location of the final depots **(Figure 6a.** and **Figure 6b.)** and the Voronoi cells, the areas of the cells and the perimeters of the cells were calculated for each permutation of the nodes containing exactly *k* elements. The best of all the calculation is memorized. In the following iterations smaller and smaller grid were laid around the last calculated best nodes **(Figure 6c.)** and in each iteration the Verona cells, the areas of the cells and the perimeters of the cells were calculated for each permutation of the nodes containing exactly *k* elements. The distance between the new nodes in each iteration was smaller and smaller: 0.8, 0.4, 0.2, 0.1, 0.1, 0.05. After the 6th iteration the preciseness decreased only till 0,7%, **(Table 1.)** so the calculation was interrupted.

	5th iteration	6th iteration
location of the seeds	{3.9,4.1} {3.2,1} {0.5,1.8} {3.3,2.2} {0.7,2.9}	{3.9,4.1} {3.3,1.1} {0.4,1.7} {3.3,2.2} {0.6,3}
areas of the Voronoi cells	3.97443 4.00662 3.98752 3.97427 4.05717	3.98523 4.01604 4.03473 3.98759 3.97641
Sum of the perimeter of the cells	40.7338	40.6964
Preciseness of the solution	0.02404798486021743	0.024217037986386948

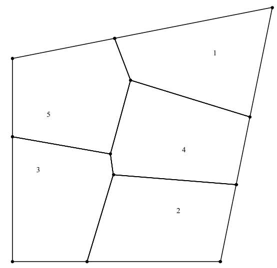
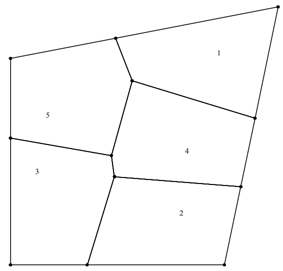
Graphics		

Table 1.

The preciseness can be given in advances where the iteration should be stopped. It means it is not the optimal solution of cutting up the area of the structure, but it is near optimal solution. After the Voronoi cells are found the best location of the final depots and the belonging total handling distances can be calculated for each Voronoi cells by any kind of two parameter optimization.

b) For human labors, when the result should not be complicated

The solution of the Verona cells *(Table 1.)* is not useful when the handling is done by humans because the labor will not be able to memorize the edges of the cells and will make mistakes in where from where to handle the material. These mistakes will result worse solution compared to the optimal solution. In this case the area of the structure should be cut only by parallel and vertical directions to one of the sides as it is usually done in practice. The main side is mostly selected in advance. If it is not selected then the longest side should be the main side. The algorithm is that only just one cut is done at a time and after each cut the solution must be checked the proportion of the sum of the perimeters and the minimal perimeter. The minimal perimeter of a cell size area belongs to the certain size of circle ***(K_C)***. If the deflection between the sum of the perimeters and the *i* times minimal perimeter is bigger than $\boldsymbol{D_e}$ (the maximum permissible deflection is given in advance) then the cut should be redone again with one (or one more) vertical cut inside and if it is not enough then the cut before should be redone with the same way *(Figure 7.)*.

The i^{th} cut:

$$If\left[D_e > D\left(\frac{\sum K_i}{i}\,\mathrm{II}K_c\right)\right], RECUT\,, continue$$

We checked this model on the example that was introduced before. The main side of the area was given in advance, the x axis. In this example $D_e=2$ was given in advance too so D in the first cut resulted a bigger solution then D_e so a vertical cut is inserted during the first re-cut *(Figure 7a.)*. The second cut resulted the same so it was redone with one vertical cut as well *(Figure 7b.)*. The third cut resulted $D_3>D_e$ too, but the third cut could not be redone so the second cut had to be re-cut again with one more vertical cut *(Figure 7c.)*.

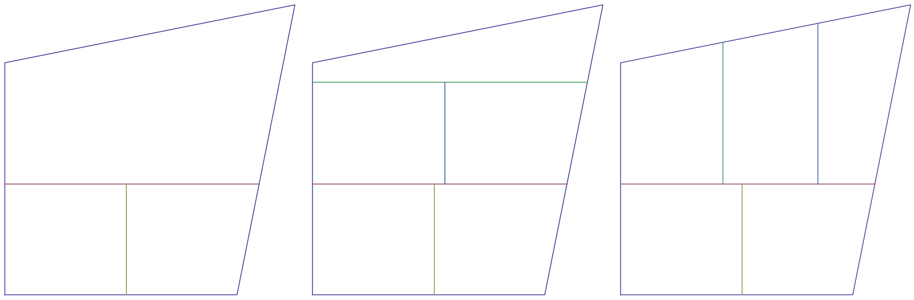


Figure 7. a) b) c)

With horizontal and vertical cutting it is the best solution so it can be called optimal solution for labors (*Figure 7.* and *Table2.*). All cells are equal area, all areas are 4 and K=41,2097 that is 1,01% worse than the Voronoi near optimal solution.

Another solution is when a net is set that fits into the area of the structure and the net's sides are equal to the minimal perimeter of the rectangle cells that have equal area to the structure's area divided by k. It will result leftover areas that should be cut parallel and vertical cuts to the net's sides. After it is done, the net should be resettled with a little bit disfigured net. It has infinite solution as well as the Voronoi regions have so the wanted preciseness should be defined in advance. This solution often results one or more concave cells that is unwanted for us *(Figure 8.)*.

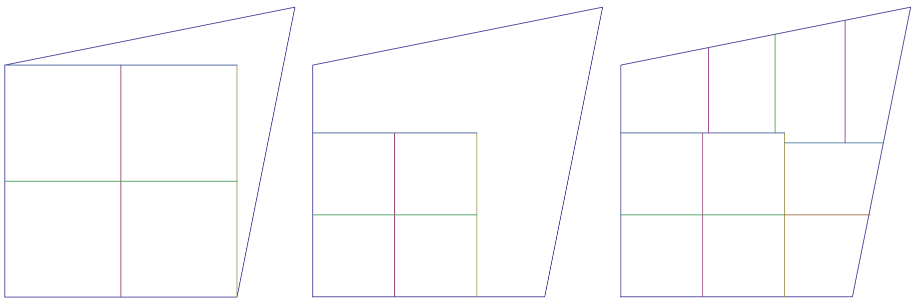


Figure 8.

6. MODEL IF THE FINAL DEPOTS MUST BE PLACED OUT OF THE AREA THAT IS SERVED BY THE CERTAIN DEPOT

In this model the feasible places of the final material depots must be out of the area that is served from the certain depot. In the technologies where this condition exists mostly the heading of the construction is given in advance like it was given for the shown boarding of the formwork of the concrete slab, because the feasible places of the depots are the ready formwork parts. In this case the model is similar to the model that is declared for human labors but the optimal length of the sum of the perimeters of the partitioned areas is searched for instead of the minimal length of the sum of the perimeters. It means that for one depot that should be placed ***d*** distance from the edge of the partitioned area, the optimal perimeter (and the optimal sides) of the area of the depot should be counted instead of the model for robots:

$$\min \sum_{1}^{i} \int_{f^d}^{f^u} \int_{x=\min A_i}^{\max A_i} \left(|y+d|^2 + \left| \frac{x}{2} - x \right|^2 \right)^{1/2} dxdy \rightarrow \min D\left(\sum_{1}^{i} K_i \amalg K_{optimal} \right)$$

$$P^i{}_{(a_i;b_i)} = \left(a_i; \frac{Area_k}{a_i} \right)$$

The rest of the model is similar to the labor's model.

7. COMPARING THE RESULTS

Both ways are hierarchical ways that means the result will occasionally be the optimal solution.

	6th iteration of the model with the grid	**Model for labors**	**Randomly generated seeds**
location of the seeds	{3.9,4.1} {3.3,1.1} {0.4,1.7} {3.3,2.2} {0.6,3}	not known not known not known not known not known	{1.60332,1.04514} {2.85648,3.18759} {3.54759,3.32483} {0.311828,2.56597} {2.9615,1.3191}
areas of the Voronoi cells	3.98523 4.01604 4.03473 3.98759 3.97641	4 4 4 4 4	4.27561 3.70286 4.07017 3.73784 4.21352
Sum of the perimeter of the cells	40.6964	41.2097	41.21038
Preciseness of the solution	0.024217037986386948	0,02426613	0.0210152

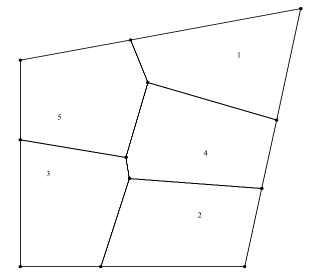
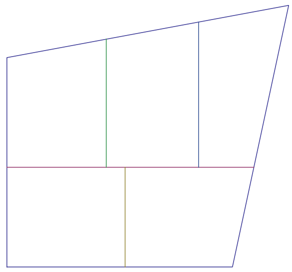
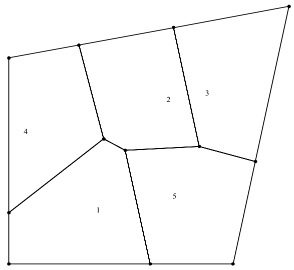
Graphics			

Table2.

The model that operates with the Voronoi regions and chooses the location of the seeds from a given nodes resulted the minimal length of the sum of the perimeters so it is the closest solution to the optimal solution *(Table2.).* But it cannot be a tool for detecting the final material depot for labors because the partitioned areas are too complicated. The model with the vertical and horizontal cuts did not show extremely worse solution comparing to the model with the Voronoi region if the number of the depots is small but it would probably worse if we increase the number of the depots.

8. GENERALIZATION OF THE MODELS

It should be noticed that the best solution belongs to the longest sum of the perimeters of the Delanuay triangulation that is dual to the Voronoi region. According to [15] whose survey is very similar to this survey should be noticed that if the number of the deposits are large k>20 then the nodes in every second line of the first set of the rectangular grid should be moved parallel to that line by a half of a grid. This way the number of the nodes in the grid can be equal to k and the number of the counting can be decreased by the number of the first permutation if the grid is parallel to the longest side of the area of the structure.

This example was solved for a convex shaped structure and the models were set for Euclidean distances, but these can deal with obstacles and concave structures exactly the same way as the discrete model does known from the literature by dividing the area up to areas named: *"visible from, partly visible from and not visible from"* [16, 17].

In this example the delivery cost was left out of consideration because the allocation of only one kind of material depots was searched for and the delivery paths were horizontal to every directions but these models can be integrated to any models of CSLP that minimizes the total delivery cost as well.

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ANALYSIS OF UNDERGROUND INFRASTRUCTURES IN AREAS OF ACCELERATED URBAN GROWTH

María L. Peralta
Universidad Tecnológica de Panamá, Panamá, maria.peralta@utp.ac.pa

Abstract

The rapid construction of high-rise buildings experienced in mega-cities around the world, commonly results on impacts on the performance of underground infrastructures. The new constructions produce significant changes on the characteristics of urban runoff, impacting the performance of the drainage system. Similarly, existing water supply systems receive intense pressure from the populations moving to the new buildings. Some critical cases can be found particularly in mega-cities in developing countries, where there is a disparity in the growth of high-rise buildings and the growth of capabilities of existing underground infrastructures. These disparities could lead to occasional interruptions of water supply in peak demand periods, and to an increased number of flood events in urban areas. Using a case study, this research analyzes the current conditions of the systems, due to the changes in surface runoff and the increased water demand. Since several variables with the potential to impact the performance of the drainage system were identified, this study proposes a scale to describe the operating conditions of this infrastructure. The scale incorporates the impact of the identified variables. Based on independent quantitative analyses of both systems, this research provides a useful tool to decision makers to evaluate the impact of high-rise buildings on the performance of the water supply and drainage systems.

Keywords: drainage system, high-rise buildings, infrastructure, water supply.

1. INTRODUCTION

The impacts of natural physical events or human interventions on critical infrastructures have been studied often in the past, particularly after the California blackouts in 2001, the terrorist attacks of September 11, 2001 (Mendonça and Wallace 2006), and the northeast U.S. blackout of 2003. A number of studies have been conducted to understand and analyze critical infrastructures and their interdependencies (Rinaldi et al. 2001; Peerenboom 2001). Critical infrastructures, particularly underground systems in developing countries, face physical threats similar to those in industrialized nations: natural disasters, man-made failures, aging, and increasing interconnectivity. However, in these countries the insufficient investment for construction, rehabilitation and maintenance of infrastructures, combined with growing urban populations constitute additional threats to infrastructure systems.

In developing nations, the growth of cities due to the movement of population from rural to the urban areas is a major infrastructure disruptor. In these growing cities, high-rise buildings play an important role, providing housing and serving commercial purposes in areas where available horizontal space is limited. High-rise buildings require services from different infrastructures, including transportation, power, water, and food supplies, in order to fulfill their role (Beedle 2004). In spite of the impacts that high-rise buildings can have on infrastructure systems, there has been surprisingly little published work to assess these impacts. Previous studies (Peralta et al. 2009) considered the impact of high-rise buildings on the performance of electric and transportation infrastructures.

A case study is used in this research to assess the impact of high-rise buildings on the performance of the drainage system and the water supply infrastructure in developing countries. The objective is to assess the performance of underground infrastructures under current conditions. The goal of this study is to provide and evaluate recommendations for the management of key infrastructures in developing countries.

2. METHODOLOGY FOR THE ANALYSIS OF THE UNDERGROUND INFRASTRUCTURE SYSTEMS

Three major phases can be identified in the methodology implemented in this research: (1) identification of major components of the infrastructure systems (inventory), (2) modeling of performance of the underground systems due to impacts of high-rise buildings, and (3) development of recommendations and mitigation strategies for managing key infrastructures. To demonstrate the methodology developed in this research, a case study (a large city in a developing country) is undertaken. A particular district of this city faces challenges in areas of infrastructure provision, including inadequacy of maintenance expenditures in critical infrastructures, leading to insufficient capacity in existing infrastructure systems (drainage and water supply). In addition, since the year 2000, high-rise buildings construction has been on the rise in the same district, producing significant changes on the characteristics of urban runoff and increasing significantly the water consumption in the areas where the buildings are located. The incorporation of high-rise buildings on the area of study is driven mainly by a rapid economic growth (commercial and residential) which forces significant changes in land-use. Areas of individual households are being replaced by buildings, 30-story buildings or higher.

2.1. Inventory of Assets of the Systems

One of the first challenges for the analysis of the underground infrastructures is the limited information about the main assets of the systems and their conditions. Data was gathered throughout site visits for a period of twelve months to create a database of the main components of the systems. The information was processed and digitalized using Geographic

Information Systems tools (figure 1). The database for each infrastructure contains important information such as lengths, diameters, materials, locations, conditions, among other characteristics of the main components.

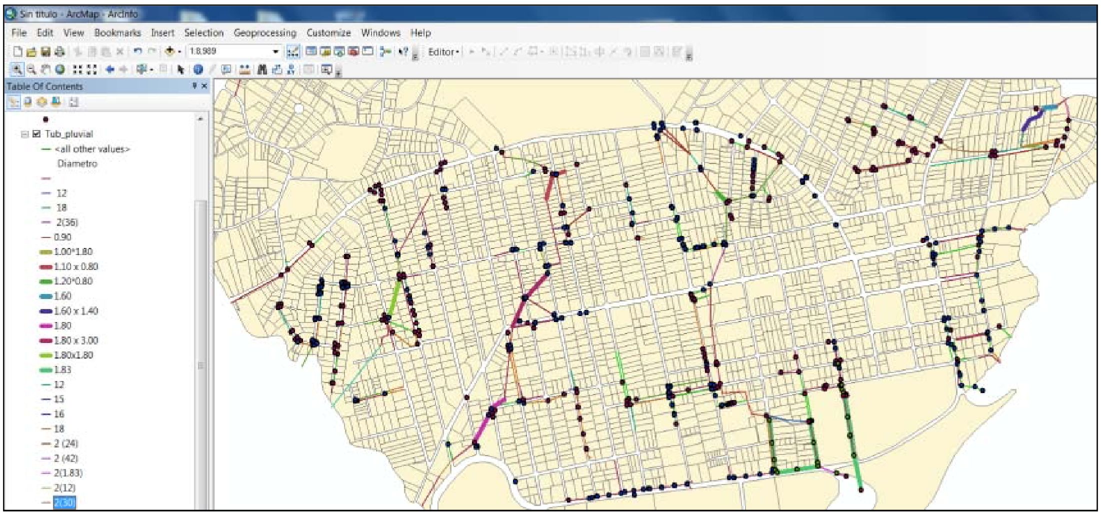

Figure 1: Database of the main components of the drainage system

2.2 Analysis of the Drainage System

The analysis of the Drainage System consists of a comparison between the design capacity of the system (before changes in land-use and the construction of high-rise buildings) and the capacity under current conditions.

The well-established equation of Chezy-Manning (Manning 1891) allows the assessment of the drainage network in terms of the flow velocity (V) or in terms of the flow rate (Q).

$$V = C\sqrt{RS} \quad \text{Chezy equation}$$

Where V = flow velocity (m/s), C = Chezy coefficient, R = hydraulic radius (m), S = bottom slope (m/m)

$$Q = VA = \left(\frac{1}{n}\right) AR^{2/3}\sqrt{S} \quad \text{Manning equation}$$

Where Q = flow rate (m^3/s); V= flow velocity (m/s); A= flow area (m^2); n = Manning's roughness coefficient; R = hydraulic radius (m); S = bottom slope (m/m).

To model current conditions of the drainage system, the study uses the Rational Method which is based on a formula that relates runoff, average intensity of rainfall for a particular length of time, and the watershed drainage area. This method allows the determination of a peak discharge from a drainage basin runoff.

$$Q = \frac{CIA}{360}$$

Where Q = discharge (m^3/s); I = rainfall intensity (mm/hr); A = watershed drainage area (hectares), C = runoff coefficient.

By using the Rational Method it is possible to model the current characteristics of the urban runoff, which has changed significantly in the area of study due to changes in the use of land. Households constructed in the area around 50 years ago, had significant spaces for backyards. These backyards have been replaced by concrete surfaces constructed for parking lots, mainly for the new high-rise buildings.

The results of the analysis capacity vs. demand for three main lines of the drainage systems are shown in table 1. The sections 1.1 and 1.2 represent parallel systems in which total capacity is the sum of the capacity of individual elements. The same is true for sections 3.1 and 3.2. As seen on the table, some sections of the system are facing serious difficulties to manage runoff for the design rainfall intensity. This has been evident even for rainfall close to the design intensities. This has caused severe flooding in areas surrounding sections 3 of the system (figure 2).

<table>
<tr><th>Section</th><th colspan="2">Design capacity

Q (m3/s)</th><th>Current runoff (demand)

Q(m3/s)</th></tr>
<tr><td>1.1</td><td>5.10</td><td rowspan="2">5.52</td><td rowspan="2">3.66</td></tr>
<tr><td>1.2</td><td>0.42</td></tr>
<tr><td>2</td><td colspan="2">2.84</td><td>2.83</td></tr>
<tr><td>3.1</td><td>1.78</td><td rowspan="2">3.20</td><td rowspan="2">3.05</td></tr>
<tr><td>3.2</td><td>1.42</td></tr>
</table>

Table 1. Performance of main lines of the drainage system

Figure 2. Severe flooding in the area of study. Source: prensa.com

In order to provide a more comprehensive analysis of the drainage system, this study proposes a scale to describe the operating conditions of this infrastructure considering other variables affecting the performance of the system. The scale includes four variable (1) presence of sediments or trash in the section of the channel or pipeline, (2) access to the section (channel or pipeline); access to inspection chambers (manholes); (4) conditions of storm drain inlets (curb inlet).

The **presence *of sediment or trash*** is measured as a percentage of the area of the section (channel or pipeline) obstructed by materials. It has been found, during the course of the study, that main lines of the drainage system are now enclosed by high-rise buildings (private properties), preventing any additions or modifications to the system. The variable ***access to the section*** measures the accessibility to channels or pipelines which is an appraisal of the current limitations to improve the conditions of the existing facilities. Due to the new constructions and inappropriate construction procedures, the access to inspection chambers has been covered by concrete or asphalt surfaces. This limits the access of crews to perform maintenance operations. This is evaluated by the variable ***access to inspection chambers***. When assessing the **conditions of the storm drain inlet,** the scale describes the conditions of the inlets and it measures the extent to what these inlets could allow the entrance of sediments or waste, that could cause obstructions on the system.

The variables are evaluated using a numerical scale, where the lower number (0) represents collapsed conditions, while the highest number (3) represents design conditions of the variable (table 2).

	Collapse 0	Severe negative effect 1	Moderate negative effect 2	Design conditions 3
Presence of sediment or trash	Total obstruction of the line due to trash or sediment	Severe obstruction. Low flow rate	Moderate presence of solid waste or sediment. Flow rate in more than 70% of the section	Slight or none presence of sediments. Flow rate in more than 95% of the section
Access to the section	Line enclosed (sealed) by permanent structures. No access	Limited access. Access only through private property	More than 70% of the section is located in public property	The section is located in public property with no restrictions
Access to inspection chambers	Inaccessibility to chambers. Enclosed by permanent structures	Some accessibility to chambers: located in private property or enclosed by non-permanent structures	Chambers are located in public property. Some work is required to access them (authorized personnel)	Authorized personnel has unrestricted access to chambers
Conditions of the storm drain inlet	Inlets are open cavities which allow access to trash (waste) and sediments. Inlets have been shattered	Noticeable deterioration of inlet. Some restrictions to the entrance of large pieces of waste	Moderate deterioration of inlets. More than 70% of the section of inlet keeps its design section and condition	Inlet keeps its dimensions. No damage

Table 2. Recommendations for a qualitative evaluation of the components of the system.

Once the variables have been evaluated, the performance of the section of the drainage systems is described in terms of the **A-D-I** scale (**A**dequate-**D**eficient-**I**nsufficient). When the average grade of the section is between 2.5 to 3, the performance of the section is graded as A-Adequate. This means that the section of the system will be able to drain the runoff water when the values of I (rain fall intensity) are equal or lower than the design value.

When the average grade is between 1.5 and 2.5 the section is graded as D-Deficient. The section of the system will drain runoff water with some difficulties. Some flood could occur in the surrounding areas, for design values of I (rainfall intensity). For average values lower than

1.5, severe flooding could occur in the areas surrounding the section of the system. Great disturbance of daily life is likely, with significant damage to adjacent properties.

When the A-D-I scale is combined with the results of Chezy-Manning equation, it is possible to have a better understanding of the performance of the section. Since the values used in Chezy-Manning are based on ideal characteristics of the section (no sediments, adequate inlets, etc.), the A-D-I scale can be used as a reduction factor for the value of Q (flow rate). The A-D-I scale was applied to sections 1.1 and 1.2 described earlier in this paper (table 1). The theoretical capacity of the sections was higher than the current water runoff. However, the average A-D-I grade of the sections was 2 or D, indicating potential of flood events in these sections.

2.3 Analysis of the Water Supply System

The water supply system analyzed in this study is a public water system with a series of pipes, storage facilities, valves and other accessories. The impacts of the new high-rise buildings on ability of the water supply system to satisfy demand, was measured as a function of pressure in nodes of the system (figure 3). To solve the flow continuity and head loss equations that characterize the hydraulic state of the network, this research uses Continuity Equation (flow into and out of each junction must be equal) and the principle of Energy Conservation. The current consumption from clients was used to model the performance of the system. The results show that all nodes satisfy the minimum pressure (20 psi) recommended. The impacts of high-rise buildings are modeled in this research as additional demand in specific nodes of the network. These nodes represent the areas where single household are being replaced by high-rise buildings.

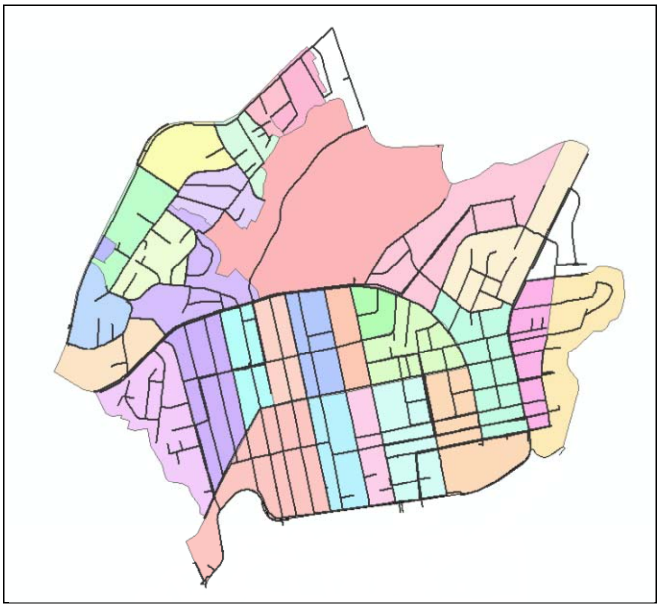

Figure 3. Water supply network in the area of study (only main pipe lines)

Further analyses are being conducted in the water supply network to create an econometric model. This model will consider additional variables (e.g. number of connections, type of connections) which could be used to make predictions about the future performance of the system. Predictions about the performance of the system will also consider different scenarios for the addition of high-rise buildings.

3. CONCLUSIONS

Findings of this study help identify the combination of factors that can intensify the impacts of high-rise buildings on the performance of critical infrastructures. This study demonstrates how insufficient provisions to increase capacity of existing infrastructures, combined with the construction of high-rise buildings, can quickly deteriorate the performance of infrastructure systems. The identification of critical system elements could assist decision-makers in allocating resources to maximize the benefits to users and stakeholders. The results of the study can be implemented during the design process of key infrastructures, in order to maximize their performance during the service life, particularly for the drainage and water supply systems. This study also provides a tool to make informed decisions about the land-use.

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AN INTEGRATED APPROACH TO SUBCONTRACTOR SELECTION IN CONSTRUCTION PROJECTS

Gul Polat
Istanbul Technical University, Istanbul, Turkey, polatgu@itu.edu.tr

Befrin Neval Bingol
Istanbul Technical University, Istanbul, Turkey, bbingol@itu.edu.tr

Atilla Damci
Istanbul Technical University, Istanbul, Turkey, damcia@itu.edu.tr

Abstract

Subcontracting is a common and well-established practice in the construction industry. It offers several benefits to main contractors such as decreases in cost and project duration, increases in profit and quality, risk sharing, etc. Due to the advantages that subcontracting promises, on many construction projects, especially building projects, main contractors subcontract 80-90% of the tasks to subcontractors. Since the large proportion of the construction works is carried out by subcontractors, the success of the overall project and the performance, reputation and survival of the main contractors highly depend on the performance of the subcontractors. Therefore, selecting the right subcontractor for the job is crucial. In the construction management literature, several studies proposed various tools, methods, and methodologies for subcontractor selection. All these studies have considerably improved the subcontractor selection process. However, some of these proposed tools, methods and methodologies are too complex and impractical to be widely accepted, applied and operated by construction professionals as they are based on computational and mathematical models and require a long learning process. Therefore, a viable subcontractor selection model should be simple, practical, and easy to use and learn. This study proposes an integrated approach, which employs AHP and ELECTRE III together, is developed to help construction companies, namely main contractors, for the selection of the most appropriate subcontractor. The proposed approach is applied to a problem of selecting the earthwork subcontractor to be worked with in a housing project in Istanbul, Turkey.

Keywords: Subcontracting, AHP, ELECTRE III, Construction Projects.

1. INTRODUCTION

A subcontractor is defined as a company that carries out specific tasks on a construction project and/or supplies laborers, materials, equipment, tools, and designs in contractual relationship with a main contractor (Arditi and Chotibhongs, 2005; Eom et al., 2008). In the construction industry, subcontractors may provide different types of services and/or resources for main contractors. Therefore, subcontractors can be classified according to the services and/or resources they supply. Mbachu (2008) classified subcontractors into three types, which are: 1) trade contractors that specialize on specific trades such as paintwork, brickwork, etc., 2) specialist subcontractors that carry out specialist services such as electrical, plumbing, insulation, etc., and 3) the labor-only-subcontractors that provide labor-only services such as skilled craftsmen. Ng et al. (2009) categorized subcontractors into two main types, which are: 1) equipment-intensive subcontractors that are predominantly hired as a result of their specialized plant and equipment, and 2) labor-intensive subcontractors that are mainly hired on the basis of their specialized labor resources.

Main contractors tend to sublet a large portion of their work for various reasons such as financial benefits, workload pressures, human or plant resource constraints, and better efficiency (Ng et al., 2009). Indeed, main contractors only control whether the work is carried out complying with the conditions specified in the main contract and related specifications while subcontractors perform the actual production work (Ulubeyli et al., 2010). Nowadays, approximately 80-90% of the tasks are undertaken by subcontractors on many construction projects, especially building projects (Hinze and Tracey, 1994).

Although subcontracting has become a very common and well-established practice in recent years, it is also a very risky practice. In the case that the majority of the work in a project is carried out by a group of unknown subcontractors, the main contractor may fail to coordinate them and control the quality and progress of their works (Cooke and Williams, 1998; Okoroh and Torrance, 1999; Kumaraswamy and Matthews, 2000; Cox et al., 2006; Karim et al., 2006; Ng et al., 2009). Since the main contractor is fully responsible to the owner for the performance of the subcontractors, selecting the right subcontractors plays a critical role in achieving project success in terms of time, cost, and quality (e.g., Shash, 1998; Arslan et al., 2008; Mbachu, 2008; Hartmann et al., 2009; Hartmann and Caerteling, 2010).

In spite of the importance of selecting the right subcontractor for the job, many contracting companies underestimate the risk of working with unqualified, incompetent, inexperienced, and insufficiently financed subcontractors and tend to select their subcontractors solely based on the lowest bid price (Tserng and Lin, 2002; Luu and Sher, 2006; Arslan et al., 2008; Mbachu, 2008; Hartmann et al., 2009). Employing incapable subcontractors may bring about additional costs such as reworks due to poor quality of work, claims, disputes, litigations, adversarial working conditions, penalties, abandonment of work, bankruptcy, etc. Thus, main contractors should take into account several factors besides the bid prices when they select their subcontractors.

The main objective of this study is to propose the integration of analytic hierarchy process (AHP) and Elimination et Choix Traduisant la Realite - Elimination and Choice Expressing the Reality (ELECTRE) III methods for the selection of the right subcontractor among a set of available alternatives considering various conflicting criteria that can be evaluated based on quantitative and qualitative data. In the proposed approach, the AHP is used to establish the decision hierarchy of the subcontractor selection problem and to determine the weights of the criteria, and the ELECTRE III method is used to rank the alternatives.

2. PRINCIPLES OF THE AHP AND ELECTRE III METHODS

2.1. The AHP Method

AHP was first developed by Saaty (1980) in order to solve technical and managerial problems. It is one of the most popular and widely used methods for multi-criteria decision making. The AHP method is especially suitable for evaluating alternatives considering several subjective criteria.

The main steps in the AHP method are as follows (De Steiguer et al., 2003; Palcic and Lalic, 2009):

Step 1: The AHP method begins with dividing the decision problem into sub-problems, which are easier to evaluate and understand. Then, a decision hierarchy is developed. This hierarchy basically includes a goal, multiple criteria, and possible alternatives. Decision hierarchies are very effective if all decision makers are involved in the development process. An AHP hierarchy can have as many levels (i.e., main criteria, sub criteria, etc.) as needed to fully represent the specific characteristics of a decision problem.

Step 2: All decision-makers individually express their opinions regarding the relative importance of elements within each level according to their influences on the specified element in the upper level using pairwise comparisons based on a standard 9-point system ranging from 1 (the two choice options are equally preferred) to 9 (one choice option is extremely preferred over the other) presented in Table 1. If one element is preferred less than the comparison element, the reciprocal of the preference score is assigned.

Level of importance	Definition	Explanation
1	Equal Importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much more important	Experience and judgment very strongly favor one over the other.

9	Absolutely more important	The evidence favoring one over the other is one of the highest possible validity.
2-4-6-8	Intermediate values	When compromise is needed.

Table 1: Saaty's Rating Scale

Step 3: Preference scores are synthesized by dividing each element of a pair-wise comparison matrix by its column total and then taking the overall row averages in order to calculate priority vectors for the elements by dividing each element of a pair-wise comparison matrix by its column total and then taking the overall row averages.

Step 4: Consistency Ratio (CR) is calculated in order to measure how consistent the judgments are. If the CR is greater than 0.1, the judgments are untrustworthy because they are too close for comfort to randomness. In this case, the pairwise comparisons need to be repeated.

De Steiguer et al. (2003) summarized the general characteristics of the AHP method as follows: (1) It is a structured decision process which can be documented and replicated, (2) It is applicable to decision situations that involves multi-criteria, (3) The AHP is applicable to decision situations that involves subjective judgment, (4) It uses both qualitative and quantitative data, (5) It provides measures of consistency of preference, and (6) It is suitable for group decision-making.

2.2. The ELECTRE III Method

The word ELECTRE stands for "Elimination et Choix Traduisant la Realite - Elimination and Choice Expressing the Reality". The ELECTRE family is one of the most popular outranking methods. The ELECTRE method was first developed Bernard Roy and his colleagues at SEMA Consultancy Company in 1965 (Tam et al., 2003). There are six main different versions of ELECTRE, namely; ELECTRE I, II, III, IV, Tri, and IS. The main difference between these versions is the type of criteria involved. The criteria can be classified into two categories: a) true criteria and b) pseudo-criteria.

True criteria fall into traditional preference structure in which there is no threshold. In the traditional preference structure, if the decision maker prefers "a" to "b", or there is indifference between these alternatives, then "a" outranks "b". This can be described as follows:

$$a\mathbf{O}b \text{ if } a\mathbf{P}b \text{ or } a\mathbf{I}b$$

where O = Outranking
P = Preference
I = Indifference

$$a\mathbf{O}b \text{ if } g(a)>g(b)$$

$$a\mathbf{I}b \text{ if } g(a)=g(b)$$

where g(a) = Performance of alternative "a"
g(b) = Performance of alternative "b"
a and b Є set A.

This type of preference structure is called a complete preorder. In other words, all possible alternatives can be ranked from the best to the worst. ELECTRE I and II use true criteria.

Pseudo-criteria involve a two-tiered threshold approach. In real life, there is often an intermediary zone in which there is no strict preference on the alternatives. In order to deal with such situations, a preference model having two different thresholds, namely indifference and preference, is used. The decision shows clear indifference within the indifference threshold. On the other hand, the decision has a strict preference on the alternative beyond the preference threshold. The area between two threshold values is defined as "weak preference "in which decision is uncertain and denoted as a**Q**b. This can be described as follows:

$$a\mathbf{P}b \text{ if } g(a) > g(b) + p(g(b))$$

$$a\mathbf{Q}b \text{ if } g(b) + p(g(b)) \geq g(a) > g(b) + q(g(b))$$

$$a\mathbf{I}b \text{ if } g(b) + q(g(b)) \geq g(a) \text{ and } g(a) + q(g(a)) \geq g(b)$$

where p(g(a)) = preference threshold of alternative "a"
q(g(a)) = indifference threshold of alternative "a".

ELECTRE III, IV, IS and Tri use pseudo-criteria (Tam et al., 2003).

ELECTRE I is designed for selection problems, ELECTRE TRI for assignment problems, ELECTRE II, III and IV for ranking problems (Marzouk, 2011). The distinction between ELECTRE methods is based on how they define the outranking relations between alternatives and how they apply these relations to get the final ranking of the alternatives (Wang and Triantaphyllou, 2008). In this study, ELECTRE III was preferred. In ELECTRE III, comparison between alternatives is carried out on a pairwise basis and the degree of dominance of one alternative over another is established.

3. A NUMERICAL APPLICATION OF THE PROPOSED APPROACH

The proposed approach is applied to a problem of selecting the earthwork subcontractor to be worked with in a housing project in Istanbul, Turkey. The project in question consists of both residential and commercial areas. The total construction area is 29,363 m^2, the estimated construction cost is 18,000,000 TL, and the anticipated project duration is 18 months. The entire project will be subcontracted in three phases, which include; earthwork (excavation), soil works, and superstructure. In the studied project, six alternative earthwork subcontractors submitted their bids.

3.1. Structure of the Subcontractor Selection Problem

The subcontractor selection process is unique for each project phase, which is mostly determined by the expectations of the main contractor and the nature of the task. In order to establish the structure of the earthwork subcontractor selection problem, the planning engineer working in this company and in charge of selecting subcontractors is interviewed. The decision hierarchy is presented in Figure 1.

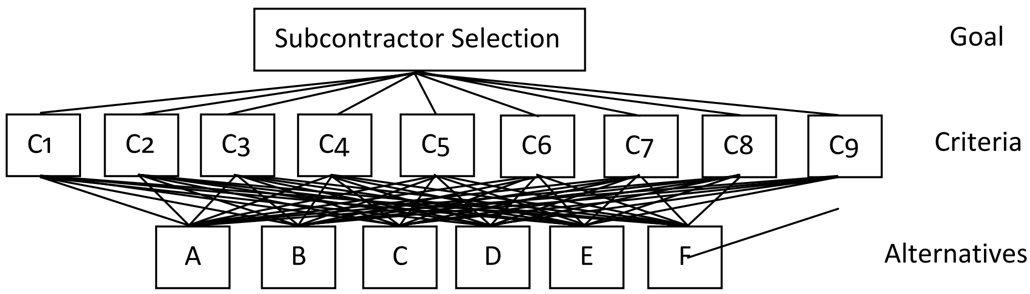


Figure 1: The hierarchy of subcontractor selection problem

In this hierarchy, C1 is the bid price, C2 is the number of excavators, C3 is the number of trucks, C4 is the safety record, C5 is the past relationships, C6 is the maximum business volume, C7 is the number of ongoing projects, C8 is the number of references, and C9 is the experience of the company. A, B, C, D, E and F are the alternative subcontractors.

The interviews with the decision maker indicated that nine criteria basically play a role in selecting subcontractors. While the alternative of the subcontractors can be evaluated quantitatively on seven of these criteria (C1, C2, C3, C6, C7, C8, and C9), they can be assessed qualitatively on two of these criteria (C4 and C5).

Quantitative data were taken from the tender documents submitted by six alternative earthwork subcontractors. In order to obtain qualitative data, the decision maker was asked to rate the alternative subcontractors on a scale of 1 to 100, where 1 denotes for poor and 100 for excellent, based on the past experience with these subcontractors.

3.2. Determining the Weights of the Criteria Using the AHP Method

After structuring the subcontractor selection problem, the AHP method was used to compute the weights of the criteria. The weight of each criterion was determined based on the decision maker's pairwise comparisons. The weights were calculated via Super Decision software program and the results are presented in Table 2. The consistency ratio was checked. Since it is lower than 0.10 (C.R = 0.03), it can be considered as acceptable.

The results indicate that "Bid Price" (C1) has the highest weight on the subcontractor selection problem. "No. of Excavators" (C2) and "No. of Trucks" (C3) have also substantial influence on the earthwork subcontractor selection. This finding is reasonable as earthwork operations are mostly carried out by equipment. On the other hand, "Experience" (C9) has the lowest impact.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	Weights (w_{ij})	
C1	1	2	3	2	4	4	4	4	7	0.27	
C2	1/2	1	2	2	3	4	5	3	5	0.20	
C3	1/3	1/2	1	2	2	3	4	3	4	0.15	
C4	1/2	1/2	1/2	1	2	3	2	3	4	0.12	
C5	1/4	1/3	1/2	1/2	1	2	2	2	4	0.08	
C6	1/4	1/4	1/3	1/3	1/2	1	2	2	3	0.06	
C7	1/4	1/5	1/4	1/2	1/2	1/2	1	2	2	0.05	
C8	1/4	1/3	1/3	1/3	1/2	1/2	1/2	1	2	0.04	
C9	1/7	1/5	1/4	1/4	1/4	1/3	1/2	1/2	1	0.03	CR:0.03

Table 2: Pairwise comparison matrix for criteria

3.3. Calculating the Outranking of the Alternative Subcontractors Using the ELECTRE III Method

The decision problem consists of 6 earthwork subcontractor alternatives and 9 evaluation criteria. The performances of the alternative subcontractors are presented in Table 3.

Criteria		Alternative Subcontractors						Weight (w_j)	Direction of Preference
		A	B	C	D	E	F		
C1	Bid Price (x 1,000 TL)	865	900	950	895	920	915	0.27	Decreasing
C2	No. of Excavators	13	6	2	3	8	5	0.20	Increasing
C3	No. of Trucks	71	33	20	40	28	30	0.15	Increasing
C4	Safety Record	60	85	70	65	75	80	0.12	Increasing
C5	Past Relationships	50	75	90	65	80	70	0.08	Increasing
C6	Maximum Business Volume (x 1,000 m^3)	1,500	200	180	220	400	250	0.06	Increasing
C7	No. of Ongoing Projects	6	3	5	4	5	3	0.05	Decreasing

C8	No. of References	38	20	10	12	15	22	0.04	Increasing
C9	Experience (years)	13	6	2	4	10	7	0.03	Increasing

Table 3: Evaluation matrix

The indifference (*q*) and preference (*p*) threshold values were used in this study to incorporate some degree of impression and uncertainty in evaluating the performance of the alternative subcontractors. The threshold values for indifference (*q*) and preference (*p*)-which are determined by the decision maker-are listed in Table 4. The thresholds were calculated using the linear equation: $\alpha * g\ (b) + \beta$. In this equation, α and β are the predefined constants. The direction of calculation was set to be direct.

Criteria	**β**		**α**
	q*	P*	q & p
C1	3000	5000	0
C2	1	2	0
C3	2	4	0
C4	-3	-1	0.1
C5	-2	0	0.1
C6	200	3200	0.1
C7	1	2	0
C8	1	2	0.1
C9	1	4	0

(q*: indifference threshold; p*: preference threshold)

Table 4: α and β values for the thresholds used in the ELECTRE III method

After determining the threshold values for nine criteria, the ELECTRE III method was carried out. The concordance index on the performance of the alternative subcontractors was calculated (see Table 5).

	A	**B**	**C**	**D**	**E**	**F**
A	1	0.75	0.80	0.75	0.80	0.75
B	0.25	1	0.92	0.58	0.71	0.94
C	0.25	0.14	1	0.53	0.19	0.08
D	0.25	0.55	0.83	1	0.48	0.59
E	0.26	0.37	0.92	0.58	1	0.61
F	0.25	0.66	0.92	0.58	0.64	1

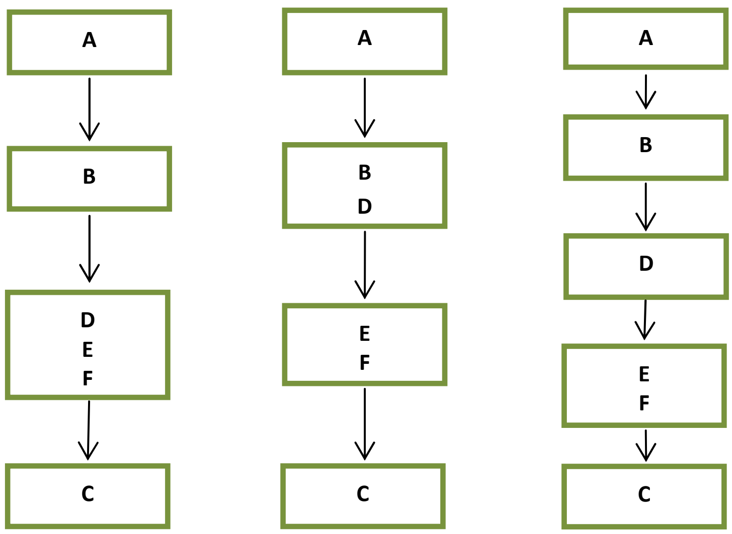
Table 5: Concordance Index in the ELECTRE III method

In order to obtain the "Descending" and "Ascending" pre-orders, the distillation procedure was applied. The combination of two ranking results gives the final pre-order of the alternatives. Table 6 shows the ranking order index of the alternatives.

	A	**B**	**C**	**D**	**E**	**F**
A	I	P	P	P	P	P
B	P^-	I	P	P	P	P
C	P^-	P^-	I	P^-	P^-	P^-
D	P^-	P^-	P	I	P	P
E	P^-	P^-	P	P^-	I	I
F	P^-	P^-	P	P^-	I	I

Table 6: Ranking index for comparison of subcontractors in the ELECTRE III method

The graphical presentation of the all ranking pre-orders is presented in Figure 2. In all ranking orders, the subcontractor "A" outranks all other subcontractors and the subcontractor "C" is the least preferred one. The subcontractor "B" performs better than subcontractors "D", "E", and "F" in the descending and final pre-orders. But, subcontractors "B" and "D" are incomparable in the ascending distillation. In conclusion, the subcontractor "A" is suggested to be the best subcontractor alternative followed by subcontractors "B", "D", "E-F", and "C", respectively, for the earthwork phase of the studied project.



Descending Ascending Final

Distillation Distillation Pre-order

(a) (b) (c)

Figure 2: (a) Descending distillation of subcontractors, (b) Ascending distillation of subcontractors, (c) Final pre-order of subcontractors

4. CONCLUSIONS

The selection of the appropriate subcontractor plays a significant role in achieving project targets. Generally, main contractors tend to select subcontractors based on their bid prices. However, this approach brings about some irreversible consequences like selecting incapable subcontractor and thereby failing to meet project requirements. The employment of incapable subcontractor may cause additional costs resulting from claims, disputes, litigations, adversarial working conditions, penalties, abandonment of work, bankruptcy, etc. Therefore, several tangible and intangible factors should be taken into account besides bid prices when selecting the subcontractor. This study proposes an integrated approach, which employs AHP and ELECTRE III together, is developed to help construction companies, namely main contractors, for the selection of the most appropriate subcontractor. The proposed approach was also applied to a problem of selecting the earthwork subcontractor to be worked with in a housing project in Istanbul, Turkey. In the studied project, the subcontractor selection problem had 9 evaluation criteria and 6 different alternatives. The AHP method was used to evaluate the weights of the criteria. Then, the subcontractor alternatives were ranked using the ELECTRE III method. Based on the findings of the ELECTRE III method, subcontractor “A” was found to be the most appropriate subcontractor and subcontractor “C” was the worst subcontractor for the earthwork phase for the project.

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INTEGRATED MANAGEMENT-MI-5 FOR SME

Nicolae Postavaru
Technical University of Civil Engineering – Construction Management dept.-investment consultant, president of Romanian Association of Cost Engineers, Bucharest, Romania, nicolae.postavaru@gmail.com

Illés Kálmán
PhD student at the Technical University of Civil Engineering, CEO at Izorep S.A., Tg Mures , Romania, illes.kalman@yahoo.com

Abstract

The theory of Integrate Management is a tool for the SME companies to help the managers to understand their role and the information they need in managing their companies.

This tool presents five domains, in which the managers must have knowledge to be able to fight the big companies, in a new organization. It is a strong fight between structures of the big companies versus competences of the SME managers.

Because there are five principal domains we call it MI-5, each has 5 subdomains and each of them include other five disciplines.

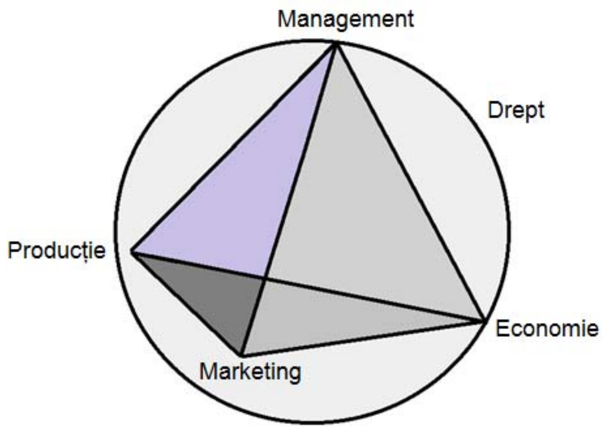

Figure: M.I.-5

This means over one hundred principal disciplines, which make the basis of knowledge and information for a manager or a new approach for management.

Keywords: management, SME, organization, information, competences.

1. INTRODUCTION

The Integrated Management Theory (1998) was born after a series of discussions with the owners and the general management analysis. I asked the employer "what does Integrated Management" mean?" He answered: "I do not know, but it sounds good. Does it sell?"

Nowadays, everything is for sale: environment, administration, defense.

2. THE INTEGRATED MANAGEMENT THEORY

We believe that it is important that through this theory we have found the answers to the following questions:

– What is management? To whom does it belong?

– Do we have a proper tool for approaching any managerial analysis problem?

The first answer is clear: the management does not belong to any profession: economist, lawyer, engineer, literate, artist, etc. It belongs to the human being and its aspirations: by nature the human wants to rule. The management belongs to the leaders.

As we will further detail, the management is composed of 4 major domains:

– decision

– activity organization

– activity planning

– Human relations in activity achievement do not belong to any specialization other than management.

And so the following question arises: is it enough, as long as we have an organization to manage, especially an SME? The answer is: NO, and here come the others disciplines and knowledge. The result is that the manager is a complex personality who has to integrate the management in many other aspects of life in order to be involved in the daily life.

You cannot be a complete manager with only management training, as well as you cannot be with only economic, engineering, military background. Or I am wrong: you can be named a manager, but not integrated in the environment. Initially, it was believed that the four components of the management belong to anybody, and this because everybody was deciding, thinking of tomorrow, and interacting with each other. Only the competition and the market fighting made the other components, organization and planning, to prove their significance, thus nowadays no one can be a good manager without assuming the two components (so we can still find them amongst us). Then people changed, became educated, and so the human relations were not simple anymore. As a result, the best decision of the moment cannot be taken by one person. The society evolution led to correct appreciation of all the management components. Before, the army was the single domain was considering this approach. Nowadays, the "battle" came to economy and all of us must be good managers if we don't want to be economically conquered.

We would like to emphasize that different types of management on the market (constructions, medical, logistic, contracting, projects, administration, legal, commercial, etc.) do not mean other than management applications in different activity domains, activity objects of their organizations. In this respect, people, processes, activities have a specific, not as the management (see the managers that switch companies only because they know management, and not the company's specific). This is why, though we integrate, we do not mix. We are convinced that the ones that understand Integrated Management, the process of it, will have from now on a useful tool in managerial analysis.

Also, in its evolution, management must be understood as passing from its educational specific (accomplishing the activity objective) to superior management, where the operational activities (human relations, practical: organization, strategic: planning) diminish, until there is a single, major one: DECISION. This is the corporate president or the general on the operations field.

We cannot all be presidents or generals.

A last idea that we embraced during the last years, seeing what is happening abroad and here: management is to be learned once you have a qualification and some experience. We do not think it is correct to appoint as manager somebody that has neither experience nor specific experience. This is why we do not advice for the management colleges, but to management master degrees. The college should provide a qualification, and some management elements: economy, human relations, organizing and planning.

In the Integrated Management Theory everything derives from two concepts that might need some clarifications – and this is done by this theory:

– the concept of a system within a company, or the company as a system, presents a systemic duality similar to the one of the light.

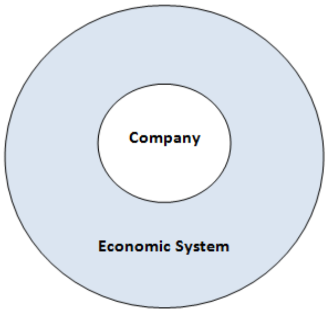

Figure 1: Systemic Duality, the cell – company and the system

Therefore, the company must be regarded as a system, as well as a cell of a system, in order to be correct. This results in specific characteristics to each form of presentation:

– cellular reproduction

– systemic complexity

If the company is a system and the economy is a system, we can go further and establish rules for the system, meaning the cells "guilty" of the different dysfunctions in the system.

Generally speaking, every human organization is the cell of a system, in which case we analyze the system, and less the cells.

If the company is a system, we can study the cell to find its DNA and see what its behavior is. In this context, by analyzing the cell we found four components embedded in the fifth. These are: management, economy, production and marketing, embedded in the legal context. We name all these elements "Integrated Management", meaning that they integrate and complete each other on company level, providing it with life and supporting the system of which it is a part. (Figure 2)

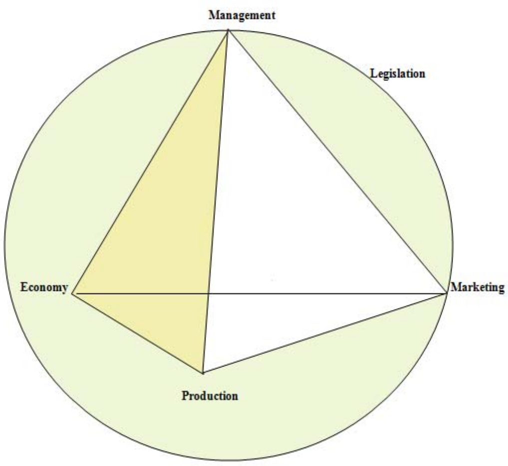

Figure 2: Integrated management = ∑Mn, Ec, Mk, Pr & Leg

This means that a company cannot be seen as a system of these elements, and that only the elements provide the image of the company.

Making a parallel organization – economic system or human – social system we get to the idea that the organization has the same principal systems as a human, that there is a medicine of the organization similar to the human medicine. What are the human systems? The respiratory, digestive, circulation, nervous and lymph system. At one point the organization treatment can be done similar to the human one, but in order to be able to do this we must thoroughly research each system. This will be done in a future presentation.

By research we discovered that each element is also a cell/nucleus of other systems. Figures 3,4,5,6 show each subsystem: management, economy, production and marketing.

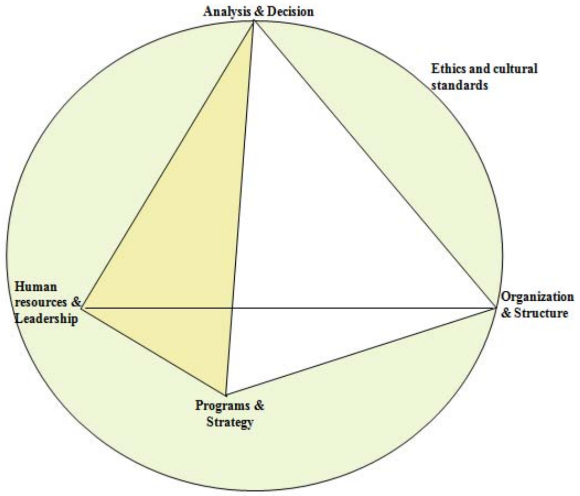

Figure 3: the Management System

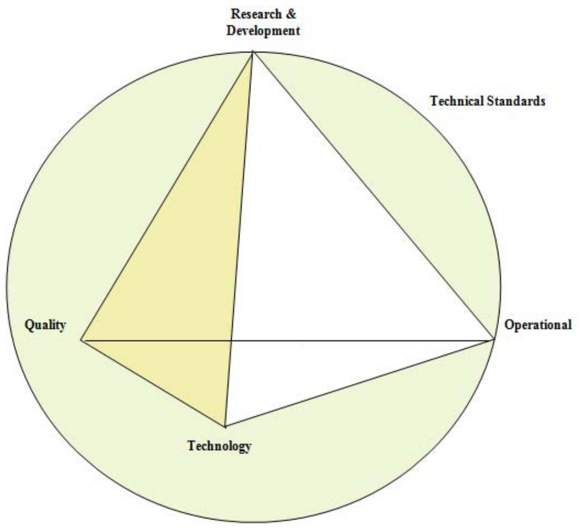

Figure 4: The Production System

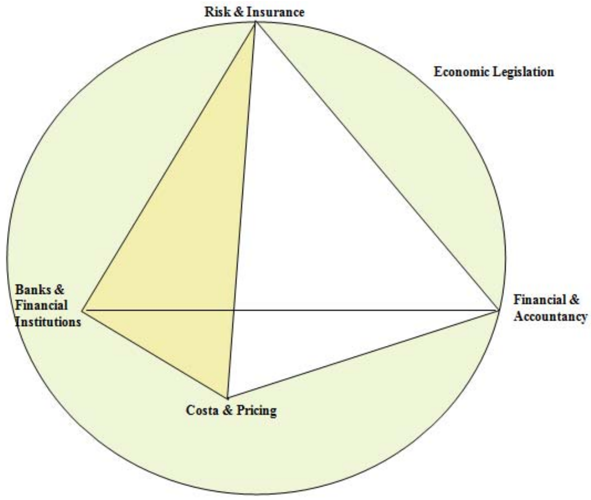

Figure 5: the Economic System

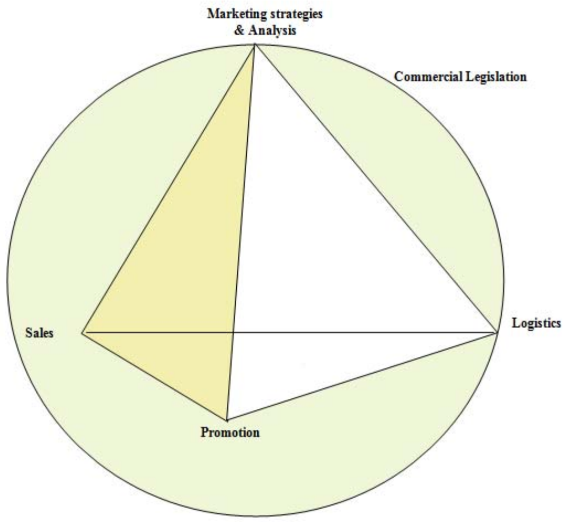

Figure 6: The Marketing System

The analysis did not stop here, but, going further we can see that each subsystem has other elements that can organize, and so we managed to establish the 5 complex elements of the Integrated Management.

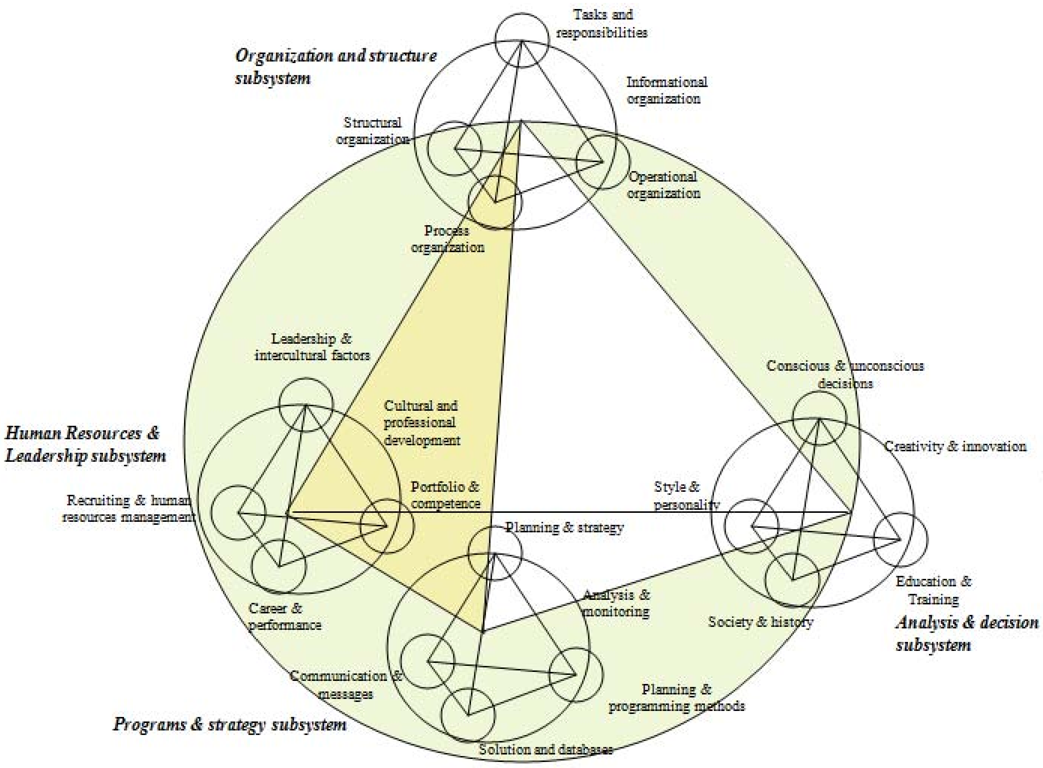

Figure 7: The management system + 4 subsystems

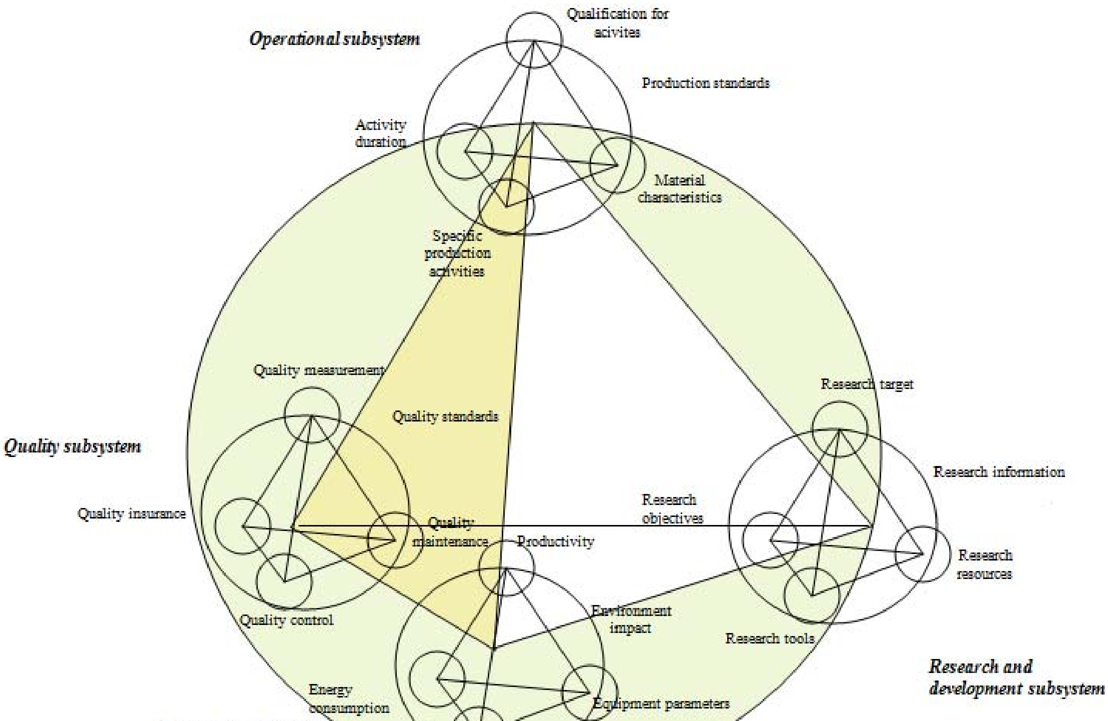

Figure 8: The production system + 4 subsystems

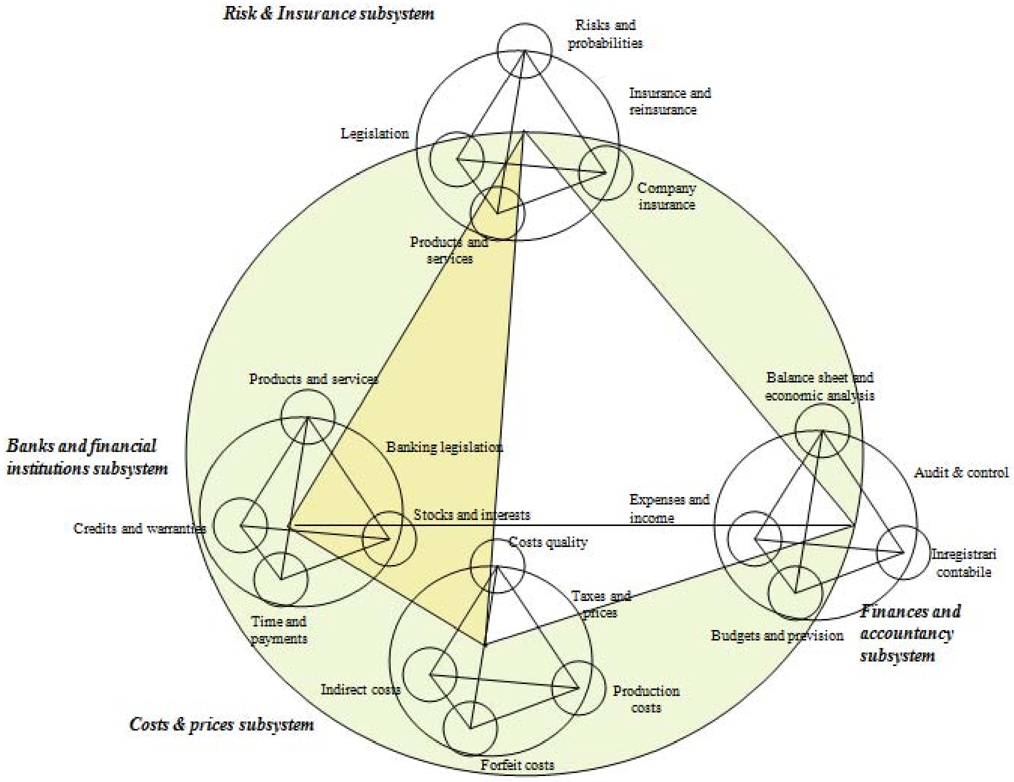

Figure 9: The economic system + 4 subsystems

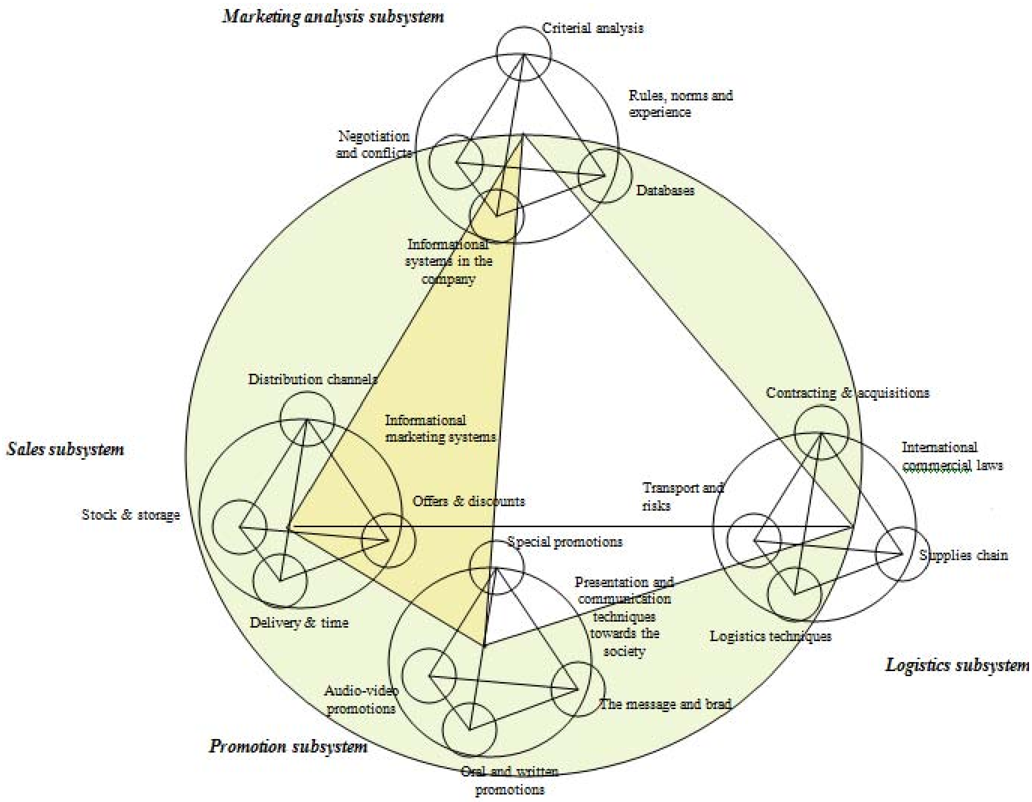

Figure 10: The marketing system + 4 subsystems

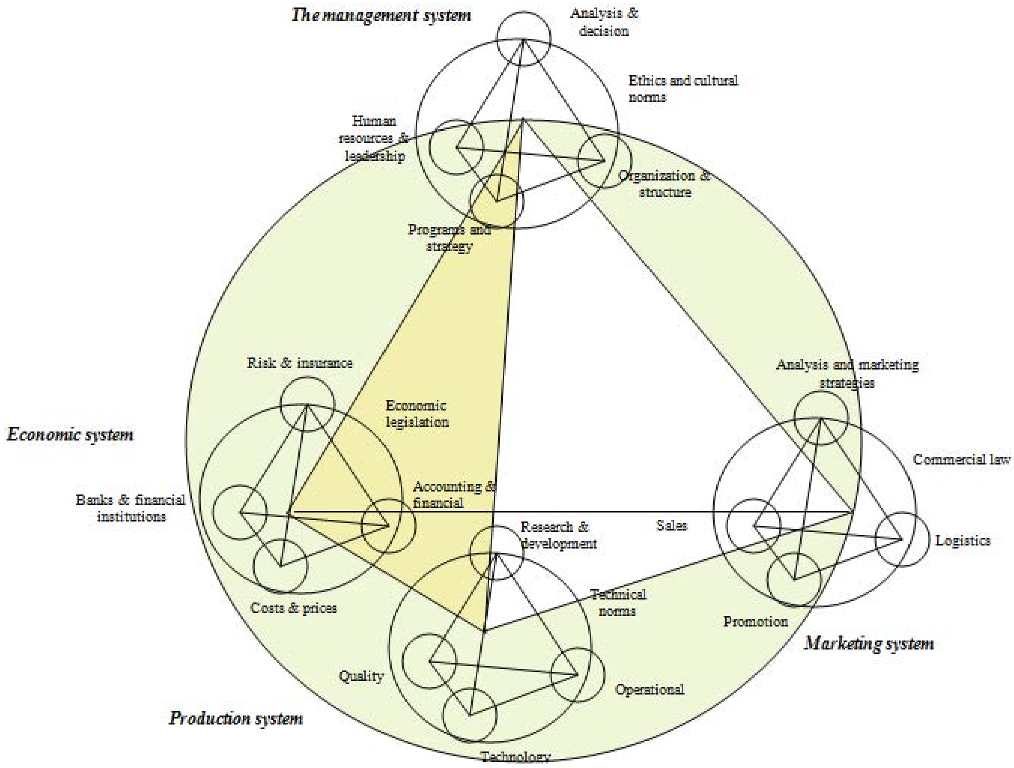

Figure 11: Integrated Management + systems + subsystems

Figure 11 shows how all the integrated systems look in one single cell. The organization is a living system in which the "cells" that it is formed of are constantly changing. Nothing is static, but the past and dead organizations.

Also, nobody can claim the paternity of the management in an organization. It is complex, and the representatives of the elements (the people) decide if the organization is alive (profitable) or merely breathing.

The theory tells us that only integrating we will be able to succeed, and, as well, that beside the other classic domains (engineering, economy, legal, medical) the management is a clearly defined domain, and that being a manager cannot be confused with being an economist, engineer, lawyer, etc. , (as it is now mistakenly associated with the economical sciences).

In constructions, for example, the management is the best distinguished by the nature of the managed people, they range from unqualified to specialized, and this can create some approach problems that are difficult to solve in an SME.

3. CONCLUSION

TMI meets the managers, showing them what they need to know and do in a company – SME, activities that in a corporation are done by specialist teams. The idea is that the problems are the same no matter how big or small the company is, and they must be handled correctly in both cases.

In a constructions company all the activities described by the theory must find a doer, and not rarely this is the manager himself.

The Integrated Management Theory addresses the people who want to become successful managers.

EXPLAINING WHAT ENABLES A PROJECT TEAM TO BECOME A SOURCE OF INNOVATION

P. Premraj

The University of Alabama, Tuscaloosa, USA, ppremraj@crimson.ua.edu

D. Grau

Arizona State University, Tempe, USA, David.Grau@asu.edu

Abstract

The objective of this study is to explain the mechanism of innovation and conditions that enables innovations driven by capital project teams through a classic change management model. Such model describes change processes within organizations and firms. The study evaluates the validity of the 8 step model process in a unique and fragmented sector like construction, and explains the innovation in equipment technologies driven by a small team of individuals in charge of a large infrastructure project. The methods include the analysis of data collected in the field –both quantitative and qualitative, and through surveys and interviews with project team members. Coupled with the literature review, the analysis of the collected data supported the comparison between the team-driven innovation processes with that proposed through Kotter's change management model. The enablers, drivers, and barriers to innovation from the project team perspective were assessed, and the innovation process determined. Each step of the classic change management model was analyzed and observations were made to establish the ability of the model to explain the innovation process. Limitations of the model were also identified and addressed so the adapted model can be used to conceptualize innovations driven by small teams of individuals within an organization or firm. The analysis of the field data also proved the high productivity benefit that the equipment innovation brought to the execution of the project.

Keywords: change management, construction methods, innovation, project management, automation, innovation drivers.

1. MOTIVATION

Construction is one of the oldest trades in the world. Formalization of the construction industry in the United States can be tracked back to the 1900's (Goodrum 2001). Increased globalization and competition has created both challenges and opportunities over the years. The unique, fragmented and project-oriented nature of the construction industry makes innovation in construction more challenging. Challenges stem from the fact that construction operations are dependent on unique designs, scattered on distant or remote sites, constantly reconfigured, and performed under highly variable environmental conditions making innovation challenging (Paulson 1985).

Innovation was predicted to become a necessity due to increasing competition to be able to meet the market demands (Tatum, 1989). Increased competition and need to improve creates a demand to innovate and to understand the mechanisms of innovation. Goodrum (2001) studied the role of equipment technology as a facilitator for improved construction productivity, whileTatum (1989) identified productivity issues and slow rate of technological advancement as major concerns. Innovation has a direct impact on productivity and state that the improvement in productivity rates from the 1920s to the 1950s can be attributed to innovations in machine power (Goodrum, 2001). Construction innovation has benefits that include social benefits (Seaden 1996), increased economic growth (Schumpeter 1934) and market growth (Slaughter 1998) to name a few.

Innovation can be of different types including technological innovation, process innovation, product innovation etc. Nam and Tatum identified the need for product innovation (1989). Goodrum et al. (2001) studied the need for innovation in equipment technology. Thomas and Bone identified supply chain management and partnering, value and risk management, and technical innovation as key areas of innovation activity.

Though there are different types of innovation available that provides opportunities for innovation in different areas of construction, poor understanding of its mechanism and lack of literature acts as a barrier to innovation. Given the need and the opportunity, constant attempts are made to improve construction innovation through adaption of technology, methodology etc., from other industries like manufacturing. Construction innovation is constantly criticized for lagging and characterized to be backward (Winch 2003). The number and magnitude of innovations in construction lags in comparison to other industries. However, it is important to consider the unique nature of the construction industry while making these comparisons. Construction responds to derived demand, strongly externally influenced, highly-fragmented, project-based, geographically focused, served by many suppliers, and high competition (Cassimatis 1969). Immobility, complexity, costliness and high risk of failure were identified by Nam and Tatum (1989) as unique characteristics of construction. The increased need for innovation coupled with the increased complexity of the industry makes the need to understand innovation processes in order to improve it vital.

The challenges and uniqueness of construction and the lag in innovation creates a need to study innovation. Several attempts were made to study the drivers, barriers and facilitators of construction innovation over the years (Tatum 1989, Mowery et al 1982, McTavis 2011, Eriksson 2007, Egbu 1998). However, most of these studies emphasizes on large construction firms (Sexton 2003) and project based and/or delivery based nature of the construction industry (Barrett 2006) creates a need to study innovation at the project level. To the best of our knowledge, the literature review available addressing innovation at this level is lacking if not absent. As such, Gann et al (2000) established the inadequacy of literature addressing innovation in project-based, service-enhanced firms.

Project teams have a unique advantage to be innovative as a result of expertise and experience of the team members. Barrett et al (2006) noted from their literature review that the construction industry is driven by unique projects and the constant creation and disbanding of project teams with each new project. Process innovation occurs on field as the result of the several problems arising on the field and these small project teams play a key role in driving innovation under these circumstances. There is little or no data available that helps understand innovation driven by project teams. There is a significant gap/absence in the literature available for process innovation. Given the need for innovation and the opportunity, and the significant lack of information about process innovation and innovation in project driven firms, there is clearly a need to address these issues. This study attempts to bridge the gap by addressing the process innovation by small project teams. Since the construction industry is project driven, understanding process innovation by small project teams can cause significant impact on improvement of innovation in the construction industry.

2. BACKGROUND

The construction industry faces many challenges including the need for improved quality, increased productivity, and improved safety. Challenges faced in construction include those related to productivity and competitiveness and the slow rate of technological advancement (Tatum, 1989). Some of the drivers of this need for improved productivity are market demand and need for customer satisfaction (Allmon et al., 2000; Sanvido, 1983; Goodrum 2001). Goodrum (2001) identified equipment technology and its changes as factors increasing productivity. Koch and Moavenzadeh(1979) attributed the increase in partial factor productivity in 1920s to the 1970s to equipment innovation. Tatum (1987) identified the need for improved productivity along with market pull or the need to perform and technological pull which demands adopting tools and technology from other industries as factors creating a need for innovation. Tatum (1991) asserts the need to innovate to be able to compete through development and effective use of new technology. Innovation in construction is 'the act of introducing and using new ideas, technologies, products and/or processes aimed at solving problems, viewing things differently, improving efficiency and effectiveness, or enhancing standards of living' (CERF, 2000, p. 2). Slaughter (1998) defines innovation as the "actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change". Characterizations have been made to classify innovation. The Organization for Economic Cooperation and Development provides a categorization at a macro or organizational level into two categories: 'technical', which includes 'product' and 'process' and 'organizational' (Anderson and Manseau, 1999). Slaughter (1998) characterized innovation as 'radical'- small and based on experience, 'modular-a change in concept within a component, 'architectural'- a change in links to other components or systems, and 'system'- multiple, integrated innovations.

Though the literature review provides some evidence to understand how innovative construction industry is, this is limited to providing only a broad outlook. Winch (1998) suggests that though there has been some innovation in construction over the years, it is still lagging in comparison to other industries like manufacturing. Winch identified the complexity involved in the construction industry as the barrier for innovation which results in this lag. Gidado (1996) mentions that this complexity is increasing continuously, thereby making the innovation process more challenging. Existence of comparatively more 'stable and standardized' markets in marketing facilitates innovation in manufacturing industry through R&D programs (Blayse, 2004). However, there is also an opinion that there is no conclusive evidence of poor innovation performance in construction versus other industries and that comparing innovations in manufacturing and construction may not be a very accurate process (Winch 2003). Innovation in construction often stems from the manufacturing industry (Blayse, 2004).

In spite of the contradictory opinions about the lag in construction innovation, there have been several attempts made to understand innovation since there seems to be no disagreement about the need for innovation. Studies have confirmed that innovation contributes significantly to increasing the contribution to the economic growth (Blayse 2004). Several aspects of construction innovation that have been studied over the years include the attributes of adopting new technology, strategies for developing innovation, the role of culture and environment in promoting innovation, and the effect of market conditions and policies (Tatum 1989, Tatum 2000, Egbu 1998, Eriksson 2007, McTavis 2011). These establish the significant need for studying innovation and help us understand the factors and environmental conditions that affect the innovation process.

Several attempts were made to understand the drivers, facilitators and barriers that affect the innovation process itself. Tatum et al (2000) identified competitive advantage, process problem, technological opportunity and external requirements as four major drivers of process innovation. External factors that are drivers for innovation include market pull, technology push, top management's attitude organizational culture, technological capabilities, and slack resources. Another classification of innovation drivers into four broad categories of innovation drivers is – environmental pressure, technological capability, knowledge exchange and boundary spanning (Bossink 2004). The need to reduce delivery time, reduce life cycle cost, and increase productivity etc., are drivers of construction innovation (Seaden 2001). Some of the factors that affect innovation can be used as facilitators to the innovation process and these include clients, industry relationships, innovation brokers (information intermediaries who help firm become aware of technologies), and procurement systems (Blayse, 2004). Apart from these, there are some other 'factors' that control the innovation process. Tatum et al (2000) identified technological risk, financial risk, and risk of rejection by workers as barriers for innovation. Lack of flexibility is also an inhibitor of innovation (Tatum 1989). Egbu et al. (1998) lists emotional resistance, lack of participation and inefficient communication as innovation growth inhibitors. Top management isolation, short time horizons, excessive bureaucracy, and inappropriate incentives were identified as some of the barriers at an organizational level (Quinn, 1985). Government regulations and regulatory policies often hinder innations (Gann and Salter, 2000; Dubois and Gadde (2002). Safety issues, time constraints, quality, restrictive nature of codes, costs of innovation, investment reluctance, institutional framework, role of suppliers etc., are few other factors that act as barriers of innovation (Yitmen 2007).

Apart from identifying innovation at the macro level, several attempts were made to study it at a more micro level –at individual level. Macro level studies attempt to explain the drivers and barriers at an organizational level. Factors like incentives and self-motivation and role of leadership in driving innovations have also been studied (Burpitt, 1997). There is a bridge between these two levels in the field of construction. Most innovations in construction happen as a response to a problem and hence the experience and expertise of the team plays a key role in bringing about the innovation. The involvement of the team members or individual employees was studied to a certain extent though significantly lacking in comparison to the other industries. As in most management studies, the role of leadership was also examined in driving innovation in construction (Nam 1995). However, literature search supports the fact that the dynamic and the role of the team itself in driving innovation has not been understood or established.

Though the literature review helped to identify the drivers, facilitators and barriers required understanding innovation process; this was not specific to small project teams. Several models were studied. One of the earliest models made an attempt to understand the overall process involved in innovation studied the overview of the innovation process (Tatum 1987). One of the earliest models used to study innovations was the linear model (Godin 2006). Slaughter (1998) gives a brief overview of five models of construction innovation which includes incremental, modular, architectural, system, and radical innovations. These were based on theories of management and economics. This shows the feasibility of adopting change models from other industries in construction. One such model is Kotter's management model which has been popular in the business world for several years and helps understand the transformation process. Koskela et al (2001) summarized that current theory of construction is an innovation and this would be yet another reason to consider a new model like Kotter's management model. From the literature review of the innovation models in construction two basic conclusions can be made – it is feasible to adopt the models from other industries to explain the innovation in construction and that no attempt was made to explain the innovation process at a team level. There is a need for a model to understand and explain the innovation process at team level.

Understanding the innovation process at a team level is key to promoting an innovation culture in construction. Project teams are the sources of most of the process innovation on field. There are opportunities to innovate on field due to a combination of favorable conditions. These include the availability of an opportunity to innovate and a skill set to utilize the opportunity as a result of the team member's expertise and experience. The team has a certain level of flexibility and autonomy that allows them to innovate to solve problems or to adapt to any changes or environmental conditions occurring on the field. One of the key facilitator that allows this kind of innovation to occur is a culture of risk flexibility in the organization and/or the team itself. One of the barriers for construction innovation is the large number of actors involved and the challenges to effective communication in large and complex projects (Barlow, 2000; Pries and Jansen, 1995; Blayse 2004).

There is a need to understand the innovation process at team level considering the opportunities driven by the team expertise and experience and the literature review suggests that there are no innovation models in construction that caters to this need. So, it is important to either develop a new model or to adopt a model from a different industry, study its adaptability to construction and to tailor it to the construction environment to be able to explain innovation by the project team. A management model developed by Kotter was identified in the literature review as a possible model to explain construction innovation (Kotter 1995). The model explains the transformation or the process of innovation through an eight step process. Kotter's management model was published for the first time in an issue of HBR in 1995 by John. P. Kotter and was later developed into a book. The book gives an overview of an eight step process that aids in creating transformations. The steps include establishing a sense of urgency, creating the guiding coalition, developing vision and strategy, communicating the change vision, empowering broad-based action, generating short-term wins, consolidating gains and producing more change, and anchoring new approaches in the culture (Kotter 1996). This study looks at the adoptability of this model to understand the process of construction innovation by small project teams by examining each step of the management model to understand the factors affecting the feasibility of using the model for understanding feasibility of the model. It also identifies the limitations of adopting the model.

3. RESEARCH OBJECTIVES

The two objectives of this study are:

1) To use a management model to understand the innovation process. The adaptability of the model in construction and more importantly, its efficiency in explaining the process of innovation driven by small project teams has to be studied. The workability of the model has to be established initially. This has to be followed by critical examination of each of the eight steps in the model to study its adaptability in the construction industry. The need for each step has to be checked and the limitations for each step have to be identified.

2) To validate the model and establish the conditions required to be able to use the model. Considering the fact that the model has been adapted from a different industry, it is important to identify the conditions or factors required to be able to successfully use the model to explain innovation in construction. The data collected is used to validate the model.

4. RESEARCH METHODOLOGY

The methods include the analysis of data collected in the field –both quantitative and qualitative, and through surveys and interviews with project team members. The qualitative data included surveys, interviews and feedback from project team members. The surveys were designed to help understand the drivers, facilitators and barriers of the innovation. Interviews were conducted to understand the innovation process. Apart from this feedback/opinions were obtained from the team members.

The questionnaire used for the purpose of data collection had two main parts. The first part included questions designed to identify the factors that affected the innovation in each case, the drivers, key players, barriers etc. Since the surveys were sent to the key players in each case, the perception of these key players were also identified. The second part of the survey included a Likert scale ranging from 0 to 10: 0 being null influence and 10 being extreme positive influence. The purpose of this part of the survey was to understand the influence of the factors/facilitators of the innovation process in each case.

Apart from the questionnaire, feedback from key players in each innovation process studied was obtained. This included detailed explanations of the situations leading to the innovation process, identification of the key champions of the process, challenges faced in implementation of the innovation, barriers, drivers etc. This part of the survey helped to identify some of the factors that were not addressed in the questionnaire.

5. PRELIMINARY RESULTS

The efficiency of the management model in explaining the innovation process driven by small project teams was examined. Since the model was adapted from a different industry and considering the unique nature of the construction industry, few conditions that made it possible to successfully use the model to explain innovation in construction were identified. The two most crucial or essential conditions were the presence of risk flexibility in the organizational culture or the project team and a certain degree of autonomy. Project teams attempting to implement a process innovation can ensure that these conditions exist in order to successfully do so. The project team and the organization itself have to have a culture of risk flexibility in order to ensure innovations. Autonomy is the relatively easier condition to establish since the project teams in construction are autonomous a certain extent and has the decision making authority.

The eight stages of the management model were analyzed using the data collected. The factors, barriers and drivers were identified from the literature review and the case studies. Some of the key drivers were identified to be corporate culture that is supportive of innovation, communication, problem solving capability of the team members etc. The data from the survey and the Likert scale ratings were analyzed to examine the significance of these drivers. Based on the collected data, an innovation model was investigated and proposed with 8 distinct steps: establishing a sense of urgency; empowering alignment; developing a vision; communicating the vision; empowering broad-based action; generating short term wins; consolidating gains; and anchoring innovation. Each step was characterized with the collected data to explain team-driven innovation processes in the capital project industry. Key innovation drivers and barriers were identified and incorporated in the model to successfully explain the behavior of project teams as a source of innovation. The need for each step and the limitations were identified.

The first step was identified as one of the most crucial for innovation to occur and its absence is one of the most common reasons for the relative lack of innovation in construction. Generating short term wins which are significant was identified to be another step in the model which was crucial for successful implementation of process innovation. The short term wins have to be fairly immediate and quantifiable. The steps that were most challenging to adapt to construction industry were the last two steps in the model. Most process innovations occur as the result of 'problems' occurring on the field and are subject to a unique set of conditions that result in a need to innovate. Under these circumstances, it requires a unique combination of conditions for the innovation to occur again or the innovation may be a onetime event. Incorporation of such innovations and anchoring it in the corporate culture is challenging. Another challenge in anchoring innovations stems from the fact that the members of the project team and its structure are different for different projects. This study also identified the factors and drivers that affect the transitioning into these steps in order to assure their execution.

Figure 1: Fixed-lead Innovation for Extreme Batter Pile- Driving

One of the innovations studied involved a pile driving project (Figure 1). The innovation involved using inverted batter pile as opposed to normal batter pile. A 40% increase in productivity was observed as a direct result of the innovation. Other benefits included reduction in onsite equipment, reduction in the labor force required, improved safety, and reduced cost without any changes in the scope of the project. After the validity of the benefits of innovation was established, the validity of the eight step change model was examined using the data collected. The expertise and experience of the project team and the presence of a potential opportunity to innovate were identified to be the factors that created a sense of urgency for this innovation to occur. A successful coalition was established and team alignment ensured in the small project team. Participation in the innovation involved everyone in the team from vendors to the construction manager. A strategy was developed to successfully implement the innovation process after considering the benefits of the innovation through brainstorming sessions. Step four of the management model involved good communication and from the feedback and interviews, it could be established that this step of the model was satisfied in the course of the transformation process. Since there was autonomy in the team and the decision to innovate was taken by the project team it can be established that step five of the management model was also valid for the innovation process. The short term wins for the pile driving innovation was also the final "win" since the transformation was limited to the project and the conditions that existed. In the case of this innovation, the last two steps of the change model were not required. In the second innovation involved in this study however involved all eight stages in the transformation process.

6. CONCLUSIONS

Overall, the model is fairly successful in understanding the innovation process in construction and provides a guideline of the steps required to drive innovation. The conditions required for the model to be workable were established. Successfully establishing a sense of urgency helps to drive the innovation process and hence is a significant controlling factor in driving innovation. The transition from obtaining short term goals to embedding it in the culture of the organization/industry was identified to be key in developing an innovation culture. The step regarding the short term wins was identified to be crucial to the innovation process. The absence of short term wins makes the challenge of driving innovations in a change resistant environment like construction more difficult.

There are some limitations associated with the model. Our findings suggest that all the steps have to be followed in the listed sequence for it to be valid. However, this was based on the assumption that the transformation process involved a major change at organizational/industrial level and was to span several months or years. Construction however is project based and project driven innovations differ considerably from transformations of the nature mentioned above. The management model was not developed based on scientific research and was not essentially validated. The model has been criticized for these limitations and for its rigid nature (Applebaum, 2012).

Despite the limitations, the model can be tailored to be compatible with the unique nature of the construction industry and can be used to understand the innovation driven by small project teams on a capital project. Based on the nature of the innovation process the necessity of the steps involved are subject to change. If the transformation is related to an innovation specific to a project and a unique set of environmental condition, the last two steps of the management model may not be applicable.

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A PROBABILISTIC APPROACH OF CONSTRUCTION PROJECT FINANCIAL MANAGEMENT

Augustin Purnus, PhD, PMP
Technical University of Civil Engineering, Bucharest, Romania, purnus@utcb.ro

Constanta-Nicoleta Bodea
Bucharest University of Economic Studies, Bucharest, Romania, bodea@ase.ro

Abstract

The actual economical context in the Central and East European countries is characterized by an aggressive competition and a lack of investments in construction area.

The classical approach of construction projects financial management in the view of the contractor involves the acceptance of a large number of risks. The lack of cash during the project progress both at the employer level but mostly at the contractor level leads to delays, penalties and loss of opportunities which are reflected in the health of project and organization. Due to the aggressive competition, the construction companies are forced to accept risks beyond their power to mitigate them. In order to win the tender, they are bidding lower prices which make them vulnerable to the unexpected events during the project, especially from financial aspects.

The paper aim is to present a probabilistic approach of construction project financial management which will help the construction companies to identify and assess timely the financial risks and to quantify the reasonable amount of financial support in order to avoid jeopardizing the project.

Using Monte Carlo Method and Three Scenario Approach on several construction projects, the current probability of financial support is computed. A Risk Evaluation Index is proposed in order to allow the construction companies to take the decisions starting the bid and during the project progress.

Keywords: Project Financial Management, Financial Risk, Monte Carlo Method, Three Scenario Approach, Financial Risk Evaluation Index.

1. INTRODUCTION

The actual economical context in the Central and East European countries is characterized by an aggressive competition and a lack of investments. In Romania, the construction works is slowly recovering, attending the level of 2007 (figure 1). Even that, the number of Romanian companies that became insolvent in the first three months of 2013 is 4472, of which 609 of them are construction companies. The number of companies that became insolvent since the crisis in 2008 is over 90,000, of which 16,404 that went into bankruptcy in 2012.

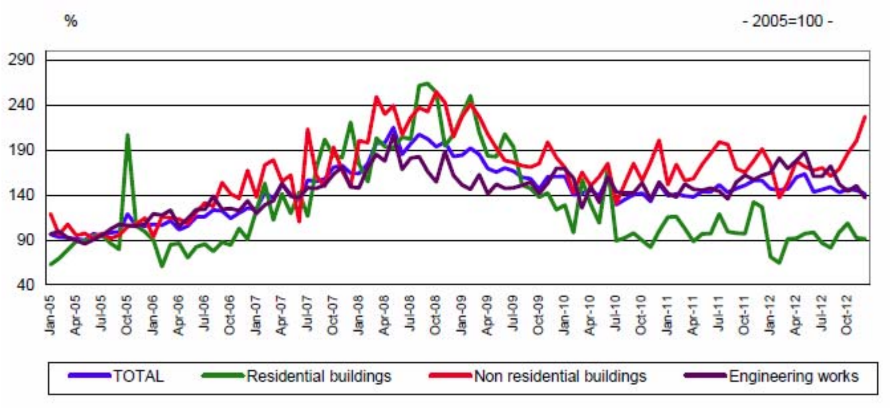

Fig. 1. Monthly evolution of construction works in Romania, in the period: January 2005 – December 2012 (Source: http://www.insse.ro/cms/rw/pages/comunicate/indici_constr.en.do)

Nowadays the concentration of the construction works is increasing; most of the construction works are done by a reduced number of companies, many of small construction companies having low success rate in bids and high chance to experience severe financial difficulties. The number of project bids is significantly reducing every year, making the competition to win projects extremely challenging. In order to win the tender, the companies accept of a large number of risks, which significantly affect the project implementation, up to their cessation. Due to the instable economic environment, the construction companies are already exposed to a large number of risks, such as currency and interest rates, inflation, credit, and other business risks.

One of the main causes affecting the project implementation is the lack of financial sustainability of the project's cash flow. Financial crisis led to the temporary cessation of payments or to major delays for interim payments in. Project sustainability is built only if the cash-in flow is timely made by the beneficiary. Otherwise, the internal financial resources of the executing company should be used, but, these companies do not have all the times these resources available. The lack of cash during the project progress both at the employer level but mostly at the contractor level leads to delays, penalties and loss of opportunities which are reflected in the health of project and organization. D. Borge (2001) considers that the unsteady economic conditions make the liquidity risk the least understood and the most dangerous financial risk because it reduces the control we have over existing risks and forces companies to assume other risks which normally they would not like to hold.

Another major cause of the difficulties of construction projects during implementation is the unsustainable biding prices. The biding prices led to a continuing erosion of the project budgets and profit margins of companies. Assign projects to values of 50% of the initial budgets have become a common practice and may encounter cases of financial offers below 10% of budgets and initially estimated. The effects that such practices have on the market are deeply negative term, as providers enter into a competition absurd prices. In the short term, companies are not able to implement projects tendered prices and reduce significantly the quality of services. In the long term, these practices lead to bankruptcy.

This is why the project finance management is becoming even more important, and managing financial risks a critical for avoiding failure in project implementation and severe financial difficulties at the company level.

2. DETERMINISTIC APPROACH

For managing project financial risks, most companies develop financial projections based on estimated financial performance of the project and the impact of the proposed project on the whole organization. For doing that, some basic assumptions are considered, such as: the time frame (the financial projections cover the project implementation period plus three-five years after the project's completion), capital outlays and financing costs (they include any up-front and ongoing capital needs during the reference period), revenues associated with the project, expenses, capital structure.

Net present value (NPV) and internal rate of return (IRR) are two of the most frequently used indicators for measuring the estimated financial performance of a project. NPV is defined as the discounted cash flows at a required rate of return (RRR). RRR represents the minimum future receipts an investor will accept in choosing an investment (Groppelli and Nikbakht, 1995). When a project has a positive NPV, the project is financially appealing. If a project has a negative NPV, there is an expected negative cash flow or the project won't generate enough cash to cover inflation and the targeted return. IRR is the discount rate required to achieve a NPV of zero. The higher a project's IRR is, the more attractive the project is financially. Many other indicators complement the NPV and IRR, such as: payback period, weighted average cost of capital, terminal value. Different works (Flanagan & Norman, 1993; Phillips & Phillips, 2006; Yescombe, 2002; Esty, 2003; Fabozzi & Nevitt, 2006) discuss about the limitations of these indicators. The sensitivity analyze is a powerful approach for understanding the project financial risk. Sensitivity analyses give the possibility to assess those variables that have the greatest risk of error in financial predictions.

For managing financial risks, most of the companies are focusing on the individual project level that does not reflect the overall risks at a corporate level. The simple sum of individual project's risks can be significantly different from the total risks of enterprise-wide perspectives (Han et all, 2004). This is why, some techniques from portfolio theory have been proposed, in order to reduce turbulent risk exposures and maximize the total value of the company (Vergara & Boyer, 1977). The basic concept of portfolio management is to reduce the overall risks associated with a portfolio of projects through diversification.

3. PROBABILISTIC APPROACH

Most of the construction companies use only the qualitative risk analysis and their decisions are based on intuition and experience, rather than an objective and detailed analysis which should be focused on performance, resource productivity, and especially the financial aspects of the organization. Therefore a quantitative risk analysis at the corporate level taking into account the organizational capacity to sustain the projects is required.

The project quantitative risk analysis is considered the hardest part of risk management, because it is based on advanced statistics and mathematics methods (Chapman & Ward, 2002). A lot of deterministic and probabilistic methods were developed over time and made available, especially through software implementation. But these methods are usually not properly applied, or not applied at all. The main reasons for this are lake of expertise, difficulties in collecting historical data, complexity of risk quantification methods, the absence of easy to use tools and also the computation effort. Two simulation methods one semi-probabilistic (Three Scenario Approach) and the other probabilistic (Monte Carlo simulation) are more and more used in construction companies.

3.1. Three scenario approach

Included in the Success Driven Project Management Methodology, the Three Scenario Approach is used together with the management by trends (Liberzon, 1996). The risk events are selected and grouped using the regular approaches in qualitative risk analysis. Three estimations (optimistic, most probable and pessimistic) are obtained for all initial project and portfolio data (duration, volume of work, productivity, calendars, resources) which will be used in rebuilding the probability curves for dates, costs, material requirement and financing (Archibald, Liberzon & Souza Mello, 2008). Defining the desired target probabilities will allow us to obtain the desired dates for finishing the project, costs, material requirements and financing. The probabilities to meet the target dates are called success probabilities and they are used to measure the buffer penetration (Liberzon & Souza Mello, 2011).

In order to build the probability distribution curve we rely on the three points with the probabilities according to the three scenarios: the point with zero probability for the optimistic scenario, the point with 100 % probability for the pessimistic scenario and the point for which the probability distribution has the maximum value (figure 2).

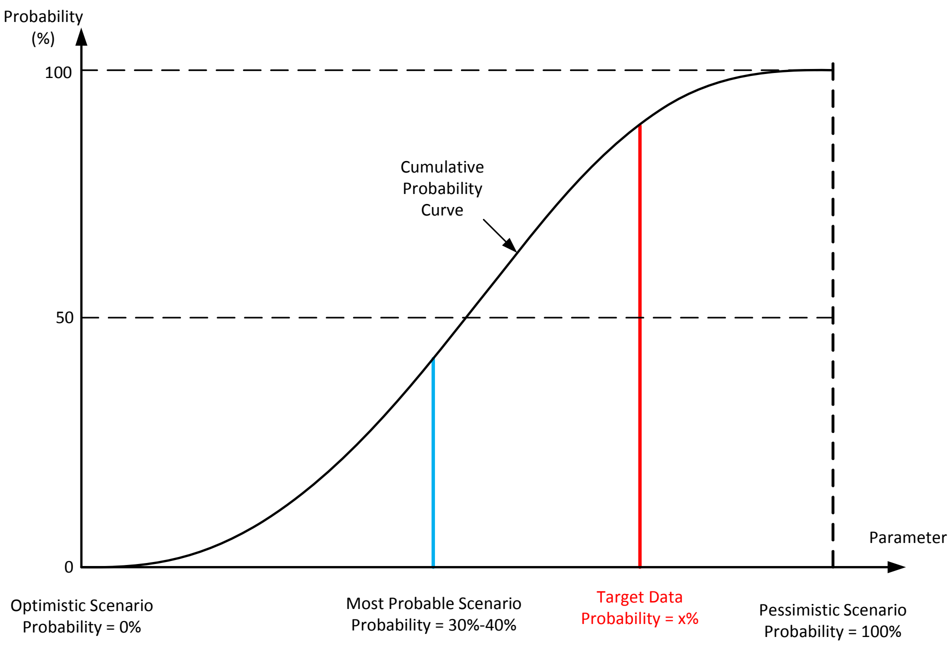

Fig. 2. The cumulative probability curve – Three Scenario Approach

During the project execution the current probability is monitor by its trend. It the probability trend is negative, than a risk event occurs and preventive or corrective measures are required. If the probability trend is positive, no action is needed.

3.2. Monte carlo simulation

Unlike the Three Scenario Approach for which there are developed three different scenarios of the project or portfolio, Monte Carlo analysis use only different estimates of the parameters. The risks events and uncertainties are simulated using triggers and conditional branches which are applied in the project or portfolio scheduling depending by a series of user defined probabilities Kendrick, 2003).

Artificial variable values are generated, using a random number generator uniformly distributed in the interval [0, 1] together with the associated cumulative distribution function. The Monte Carlo method uses the obtained results to extract values from the probability distribution that describes the behaviour of the stochastic variable.

The cumulative probability curve is build similar to the Three Scenario Approach and the probability of the target data is determined (fig. 3).

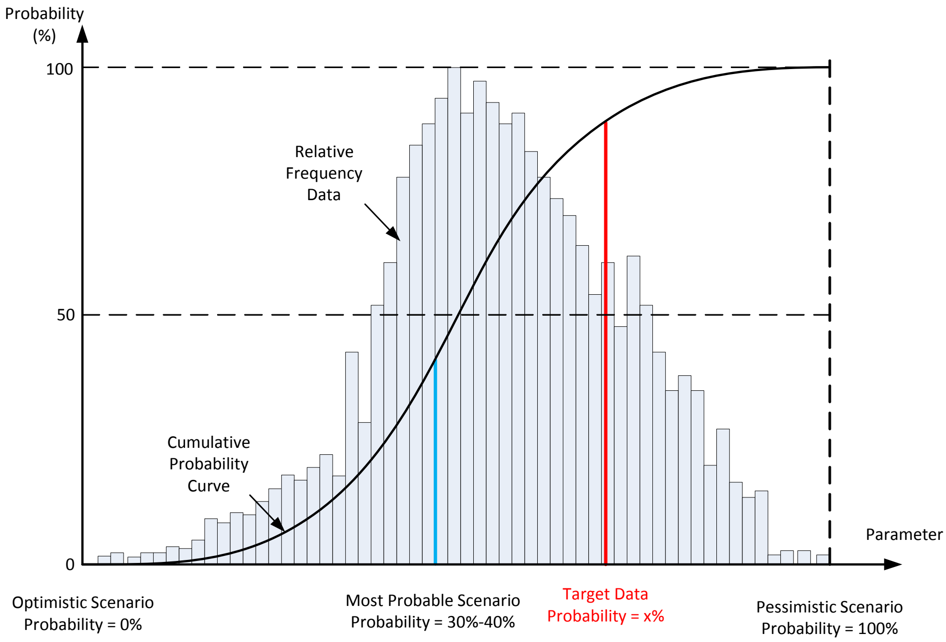

Fig. 3. The cumulative probability curve – Monte Carlo simulation

Due to the large number of iterations, the great amount of time for the preparation of input data and the large effort and time for computation, Monte Carlo simulation may be applied on projects or portfolios with a low level of detail. However, this approach will affect the accuracy of the results (Hulett, 2009).

4. CASE STUDY

The financial risk analysis was made on a project portfolio of a construction company specialized in industrial constructions for the building and equipping of five production facilities. The projects are developed for the same investor, the technical design is similar with differences in the size of the facilities, the contractual conditions are identical and the designer and the consulting company are the same for all projects. The contract is turnkey with a maximum guaranteed price.

Managing financial risks involve among other aspects, to determine at what extend the company is able to sustain with finance the construction of all the projects and to identify if external financial sources are needed. In this respect, after the risks identification and prioritization for all the projects, three scenarios (optimistic, most probable and pessimistic) were developed.

The portfolio model consists of 1362 activities, with 97 resources (manpower and equipments), 130 multi-resources, 360 materials, 164 cost components, 25 calendars and 100 cost centers.

The projects were scheduled in accordance with the contractual requirements as following (Fig. 4):

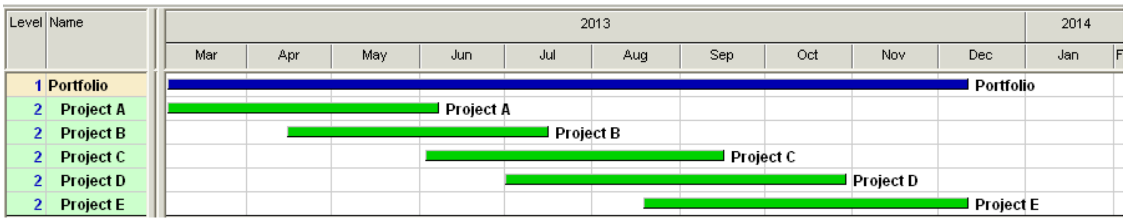

Fig. 4. Project Portfolio Gantt Chart

Taking into account the contractual clauses related to the payment, for each project, the incomes and the payments were forecasted.

The payments were grouped into two categories:

a) Payments at the project level consisted from payments for materials, equipments, site organization, sub-contractors and project overheads
b) Payments at the portfolio level consisted from payments for salaries and company overheads

As result, the cash flow for payments - incomes at the portfolio level shows as in the Fig. 5:

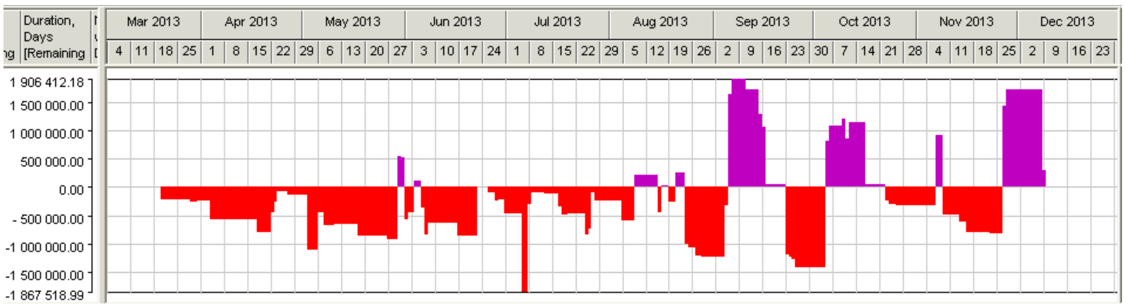

Fig. 5. Portfolio Cash Flow Payments - Income

The amount and timing of finance needed in order to compensate the negative cash flow was analyzed for each project and at the portfolio level in all scenarios (Fig. 6).

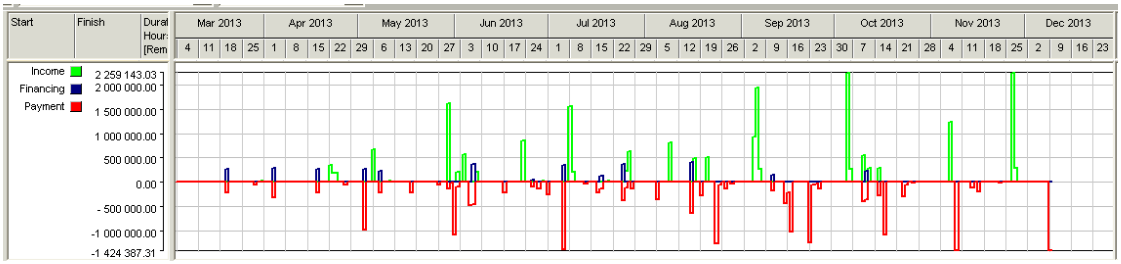

Fig. 6. The distribution of Income, Financing and Payments

In table 1 are presented the expenses and the finance required for optimistic, most probable and pessimistic scenarios.

Project	Expenses			Finance		
	Optimistic	Most Probable	Pessimistic	Optimistic	Most Probable	Pessimistic
Portfolio				546,995	904,614	1,410,079
Project A	2,867,337	2,933,222	3.057.207	564,965	1,102,082	1,483,800
Project B	3,075,500	3,141,282	3.264.665	920,957	1,303,788	1,547,157
Project C	3,413,053	3,489,119	3.632.082	399,362	1,660,029	2,183,921
Project D	3,834,995	3,936,686	4.099.429	537,368	1,763,646	2,225,899
Project E	4,220,885	4,314,280	4.378.270	374,032	801,697	1,864,220
Total	17,411,770	17,814,589	18,431,653	3,343,679	7,535,856	10,715,076

Table 1: Expenses and finance required for optimistic, most probable and pessimistic scenarios

In order to quantify the reasonable amount of financing for the portfolio with a feasible probability to be achieved, we considered the risk tolerance of the company and applied the Three Scenario Approach.

The resulted cumulative probability allowed us to set the target probability at 71.4% corresponding to the amount of 8,000,000 Euro (Fig. 7), which represent 44.9% from the most probable scenario expenses.

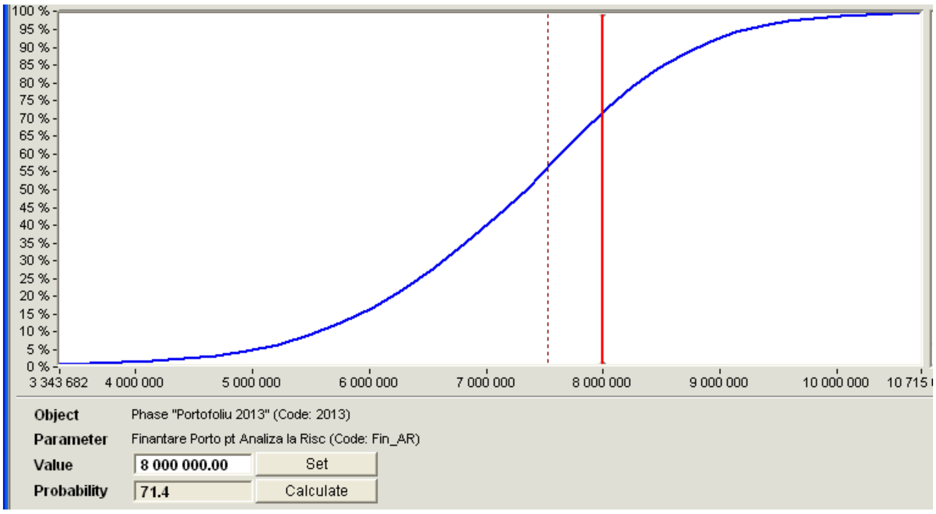

Fig. 7. Cumulative Probability Curve at the Portfolio level

It should be mentioned that this amount of financing is needed during the execution of all the projects. However, different projects will have different needs for financing and therefore, for each of them we defined a target amount of financing.

The internal financing and the target probabilities are presented in the table 2.

Project	Financing	Target Probability
Portfolio	1,015,000	70.3%
Project A	1,152,000	71.1%
Project B	1,330,000	71.1%
Project C	1,657,000	71.0%
Project D	1,769,000	74.9%
Project E	1,077,000	70.2%

Table 2: Target Probability and Internal Financing

Project and portfolio performance is monitored basing on the optimistic scenario and using the success probability trends. Due to the occurrence of risk events during the first 3 months of construction execution and mainly due to the delays in payments, the amount of financing increased from 3,343,679 Euro to 4,060,944 Euro, which represent an increase of 21.45% (Fig. 8).

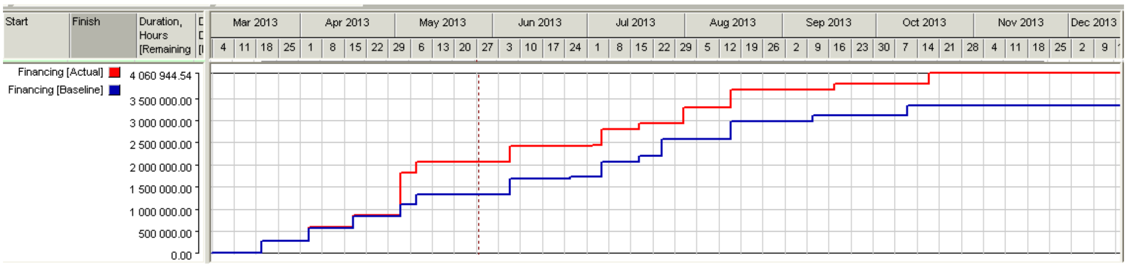

Fig. 8. Portfolio Financing - Comparison Actual versus Baseline

The impact of the risk events is the reduction of the success probability at the projects and portfolio level (Fig. 9).

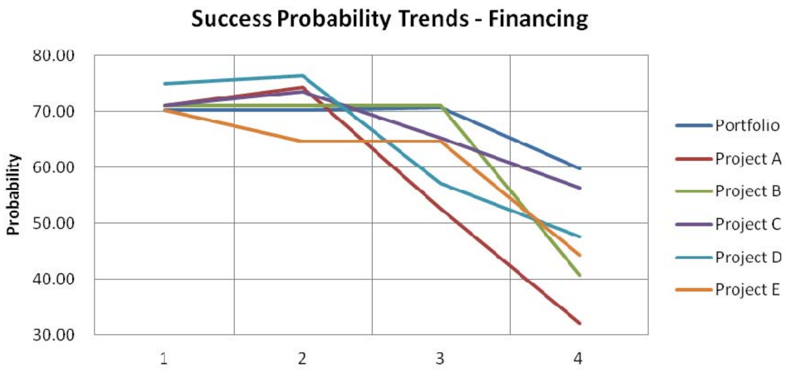

Fig. 9. Success Probability Trends

The negative trend will be followed by the decision to use additional amount of money to finance the projects, or to postpone some payments in order to avoid the negative cash flow.

During the execution when most of the risks occurs, the often changes of the projects priorities within the company portfolio will lead to changes in resource availability. The decisions are made mostly based on the company financial capability to sustain the entire effort. The research to model probabilistic financial aspects of the construction projects into one single indicator, a Financial Risk Evaluation Index is still ongoing.

5. CONCLUSIONS

The classical approach of construction projects financial management in the view of the contractor involves the acceptance of a large number of risks. A probabilistic approach of construction project financial management in order to identify and assess timely the financial risks and to quantify the reasonable amount of financial support for the projects was presented.

The complexity of construction projects and the large number of risk events and uncertainties which may occur before and during their execution make very difficult to evaluate the projects and portfolios using a single parameter. Even so, the decision to participate to tenders is based on many criteria like economical conditions, market share, market prices, type of project, type of contract, project duration, the time allocated to prepare the tender, the company financial "health", the need to win the tender, the available resources, the estimated price, the available technologies and so on.

During the execution when most of the risks occurs, the often changes of the projects priorities within the company portfolio will lead to changes in resource availability. The decisions are made mostly based on the company financial capability to sustain the entire effort. The research to model probabilistic financial aspects of the construction projects is still ongoing.

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ADAPTIVE REUSE OF THE 1996–2008 SUMMER OLYMPIC VENUES

Andrew Roberts
Auburn University, Auburn, AL, USA, acr0008@auburn.edu

Anoop Sattineni
Auburn University, Auburn, AL, USA, sattian@auburn.edu

Abstract

Modern day Olympic games require a large number of venues to host the various sporting events, as well as to house the athletes and officials. The costs incurred by the host cities to construct these structures are enormous considering the short length of the games. Many of these venues are designed with certain reuse capabilities to minimize the chance of these large structures becoming white elephants, post-Olympics. The aim of this paper is to conduct a comparative analysis of the adaptive reuse of the 1996-2008 Summer Olympic Games' major venues. The paper briefly describes what venues are needed to host a modern summer Olympic Games, as well as describing what was built in these specific host cities: Atlanta, Sydney, Athens, and Beijing. A methodology to compare the successful reuse of Olympic venues is presented in this paper by the development of a comparison matrix. A points based comparison matrix is developed which takes into account various qualitative and quantitative criteria to rank the adaptive reuse of the Olympic Stadium, the Olympic Village and the Olympic Swimming facilities. Unique aspects that contributed to the design and location of the venues of the four cities is acknowledged in the matrix. The results are noted as to how these cities are measuring up in terms of utilizing these structures. The conclusion provides recommendations for future host cities and their venues after the 17-day event is concluded. The results indicate that the adaptive reuse of the Olympic facilities of Atlanta were the best, followed by Sydney, Beijing and Athens in that order.

Keywords: Olympics, Venues, Adaptive Reuse, Comparison Matrix

1. INTRODUCTION

The Olympic Games have become one of the largest worldwide attractions over the past several years, and the amount of preparation that goes into hosting the Games is substantial. "Staging the Olympic Games represents a long and expensive commitment of a city to this mega event," Richard Cashman writes in his Impact of the Games on Olympic Host Cities (2002). He goes on to say that the impact is easily viewed in four sections. He states that the four sections are the preparing of and winning of the Olympic bid, seven years of preparing for the Games, the hosting of the Games, and the extended post-Olympics era. The goal of this paper is to break down Cashman's fourth section, the time from the extinguishing of the Olympic torch, forward.

Since the 80's, the Olympics have gotten substantially larger with every new Olympics, hosting more and more sports, and thus more athletes (Cashman, 2002). Thus, the need for a larger numbers of venues, and more colossal structures has also increased. In the four most recent summer Games, an extremely large amount of venues have been built. While the purpose of venues is to put on a brilliant atmosphere for the athletes to compete in and for the world viewers to admire, the use of these venues after the Olympics may be the most important aspect to consider. While the initial structure should apply to the venue's Olympic use, the design should also be integrated with the intended future life of the venue ("2008 Beijing Olympic Games Action Plan," 2008). In this paper, the venues of the four most recent summer Olympic Games prior to the London games in 2012, from Atlanta to Beijing will be addressed.

The Olympics have the ability to be a sprinting block towards a future of economic and worldwide hierarchy for a city, but can just as easily leave a city bankrupt, crumbling, and wishing to wake from its current nightmare (The Independent, 2008). The ability of a city to reuse all of its new, state-of-the-art venues is the key determinant on the resulting positive or negative effect the Olympics will leave on a city.

This paper will seek to provide a comparative analysis of these most recent summer Games, by comparing the adaptive reuses of each host city's major venues. A properly designed venue will not only be useful for the Olympics games, but also be marketable for use after the Olympics ("2008 Beijing Olympic Games Action Plan," 2008).

While many venues are needed for the Olympics to host the ever growing number of sports and athletes, this paper will only compare three of the games' main venues. The first venue analyzed will be the main Olympic stadium, in which the opening ceremony is held, many of the major sporting competitions, and the each Games' closing ceremony. The need for the reuse of the Olympic stadium is crucial, as it is the largest single structure built, and is often the face of the entire Olympic Games. Second, each city's aquatics facility was compared. The amount of reusability that each city's aquatics facilities hold is essentially unlimited if planned and executed properly. Finally, the last venue that was compared is the Olympic Village. Each city has an Olympic Village which hosts the thousands of athletes that participate in the Games. If properly utilized, this Olympic Village can regenerate an area or sprout an entire new community that could have never been funded without Olympic dollars. The importance of these three venues, and that fact that every Olympics in recent history has all three of these, are two factors why these specific venues were chosen.

A comparative matrix has also been developed to take many of the reuse statistics from these specific venues and will be used to see how each of these Games stacks up against the other three. Many aspects will be considered, including the number of visitors yearly to each venue, the number of events held, and the occupancy rates. Once all of the analyses have been made and the results noted, the matrix will help to provide non-biased information as to how exactly these Olympic venues are doing in terms of reuse.

2. OLYMPIC VENUES

When a city decides to submit a bid to host the Olympic Games, it should be fully aware of the responsibilities that come with the awarding of the Games. A successful plan, not just for the hosting of the Games, but for the future life of the city, must have a "well-developed plan by research, which enables it to gain ongoing benefits and to reduce possible ongoing burdens" (Cashman, 2002). This paper seeks to explore that statement to competitively rank the cities of Atlanta, Sydney, Athens, and Beijing.

2.1. 1996 – Atlanta Olympic Games

The main structure that was built was called the Centennial Olympic StadiumThe 85,000 seat stadium was built, but from the beginning a future purpose was agreed upon. The Atlanta Braves, Atlanta's Major League Baseball team, was brought in to help with the design, because Atlanta knew the ultimate life of this structure would be as a baseball stadium (Sandomir, 2005). Atlanta was also in need of a venue to hold the various swimming events that are held in the Olympics. In line with the idea of future use, the city decided to use the existing facilities at the Georgia Institute of Technology as their aquatics facility. Georgia Tech's large campus in the middle of downtown Atlanta hosted the swimming and diving events (Georgia Institute of Technology - Olympic Aquatic Center - A Counsilman-Hunsaker Project, 2012). The new improvements to the center were designed, and the newly improved venue was completed in 1994. The center had Olympic pools with moveable floors, as well as the diving platforms (Georgia Institute of Technology - Olympic Aquatic Center - A Counsilman-Hunsaker Project, 2012). The center had a capacity 14,600 and also had a temporary pool that was used for the water polo competitions that sat 4,000 spectators. The Aquatics Center played host to the following competitions: swimming, diving, synchronized swimming, and water polo. The third and final venue to be analyzed is Atlanta's Olympic Village. The Olympic Village was built using partly existing and partly new structures and is also located on the campus of Georgia Tech. Using a university site as the Olympic village was done to help ease the village into a second life, post-Olympics (Soloman, n.d.).

2.2. 2000 – Sydney Olympic Games

At the forefront of the venues that needed to be constructed was the Olympic Stadium. Sydney's lack of a stadium that could hold crowds of over 45,000 was the major contributing factor in the decision that a new stadium was to be built (Searle, 2002). Olympic stadiums need to be of substantial size to accommodate the Games, and so construction began on Stadium Australia. The proposed plan was to build the stadium to accommodate 110,000 fans to be able to hold the large crowds that would gather for the opening and closing ceremonies, as well as many of the sporting competitions in between (Searle, 2002). The stadium was built in Homebush Bay, the site of the Olympic Park. This site was selected for its size, centrality, and lack of development in the area (Searle, 2002). The Sydney

International Aquatic Center played host to all of the swimming competitions for the 2000 summer Olympic Games. It too, is located in Homebush Bay, just a short walk from Stadium Australia. The International Aquatics center included the ten-lane, fifty meter Olympic pool, a smaller utility pool, and an eight-lane training pool, with a capacity of 15,000 people. The site of the Village, which was the largest single project in the preparation for the 2000 Games (Newington, 2000), offered the athletes a mere 15 minute walk to the center of the Park, and was located only five miles east of Sydney's central business district (Soloman, n.d.). The village consisted of many different types of living facilities. There were a total of 1,213 permanent residences built in the village, as well as a few hundred temporary modular homes (Newington, 2000).

2.3. 2004 – Athens Olympic Games

At the heart of the Athens Olympic Sports Complex (OAKA) lies Athens' Olympic Stadium. The stadium was existing prior to the Games, but was upgraded for the Olympics and at the time of the opening ceremony, could seat 72,000 fans. During the 2004 Games, the opening and closing ceremonies, soccer matches, and other athletic events were held in the stadium ("2004 Olympic Summer Games venues in Athens" n.d.). The stadium is situated on a 127,625 square meter plot of land, located fourteen and a half kilometers from the Olympic Village. The Athens Olympic Aquatic Center is located in the Goudi Olympic Complex, which is situated in the Athens Olympic Sports Complex (OAKA), near the Olympic Stadium. Originally built in 1991, to host the '91 Mediterranean Games, it was expanded for the 2004 Olympics. The Center, by the time of the opening ceremony had three major pools, one indoor and two outdoor. A total of over 23,000 people could be accommodated in the venue. Swimming, diving, and water polo events were held in the center ("2004 Olympic Summer Games venues in Athens" 2004). Athens' Olympic Village, intended to host the competing athletes, trainers, coaches, and officials, too, was completed just in the nick of time. At its opening on July 30, 2004, the Village was comprised of 2,292 apartments constructed in a community style suburb. At the time, it was the largest real-estate development effort in Greece's long history (Soloman, n.d.). In addition to the living accommodations, the Village offered much more to the residents for their comfort and entertainment while staying in Greece.

2.4. 2008 – Beijing Olympic Games

The National Sports Stadium in Beijing, commonly referred to as the "Bird's Nest", served as the main Olympic Stadium for the 2008 Games. The design consisted of over 42,000 tons of steel (JSO Valuation Group, 2007), interwoven together in an elaborate feat of structural and architectural genius. The National Stadium is situated in the middle of Olympic Park, and had a maximum capacity of 91,000 at the time of the 2008 Games. It played host to the opening and closing ceremonies, as well as soccer matches, and multiple track and field events ("2008 Beijing Olympic Games Action Plan," 2008). Beijing built a near equally impressive structure in its National Swimming Center within the Olympic park. Known as the "Water Cube," because of its elaborate underwater-like, bubbly skin, this aquatics center held 17,000 fans and was the main venue for all swimming related events ("2008 Beijing Olympic Games Action Plan," 2008). Like all Olympic Villages previously, this village was the residential venue built to house and entertain the athletes and officials during their stay in China. The village was located just one and a half miles from the Bird's Nest and Water Cube (Soloman, n.d.). In order to host the 17,000 athletes, 1800 apartments were constructed in forty-two buildings (Soloman, n.d.).

3. COMPARITVE MATRIX

In order to properly compare the reuse of the selected venues, a comparative matrix, consisting of three separate comparisons, was developed. A key to a well-designed comparative matrix is to take similar qualitative and quantitative statistics of the objects being compared. The complete matrix compares the reuse of each city's Olympic stadium, Olympic aquatics center, and Olympic Village. Many of the statistics will determine a score for each city's reuse. In all, each city will have a minimum of twenty-five points up to a maximum of one hundred points. The Olympic Stadia comparison and the Olympic Village comparison will offer forty possible points each, ten minimum. The Stadia comparison will have five graded categories, eight points maximum, and two points minimum. The Village comparison will have only one graded category offering forty points maximum, and ten points minimum. The Olympic Aquatics Center comparison will offer a maximum of twenty points each, with a minimum of five, with only one category taken into account.

The first individual comparison will compare each host city's Olympic stadium. Data from 2010 and 2011 was used in the comparative matrix, as it relates to the usage of facilities, events held and visitors. The comparison matrix is shown below in table 1.

Complete Scoring Matrix								
	Olympic Villages Centertliations Olympic Stadium					*Olympic Aquatics Center*	*Olympic Village*	
Place	**Professional Sports Affiliations**	**Events**	**Visitors**	**% of Capacity/ Event**	**Visitors/ Population**	**Visitors/ Year**	**Occupancy Rate**	**Total Score**
1st	8	8	8	8	8	20	40	**100 (max.)**
2nd	6	6	6	6	6	15	30	**75**
3rd	4	4	4	4	4	10	20	**50**
4th	2	2	2	2	2	5	10	**25 (min.)**

Table 1. Comparison Matrix

Several reasons exist as to why the proposed matrix is appropriate to compare the performance of the Olympic venues. As the face of the Olympics and its venues, the main Olympic stadium is weighted heavily. At forty percent of the overall matrix, the stadium plays a large role in determining each city's reuse. Such a large cultural and national icon, the main stadium has the ability to offer a city an enormous amount of benefits if reused effectively. Large scale events, national sporting events, and international sporting events are just a few ways that the stadium can impact and affect the identity of the city. Whereas an empty structural giant, decaying daily from non-use, can tarnish a city's global standing, as well as rob them of the benefits of a well-used structure. The next forty percent of the scoring is seen in the Village comparison. The Olympic village is a huge undertaking and requires more land than any other venue. A properly reused Olympic village can rejuvenate an entire area, or spring up a new bustling community. The overall size and influence of an Olympic village is the reason behind its large percentage of the complete matrix. The final twenty percent of the scoring factor is found in the aquatics center comparison. While still important to an area, an Olympic Aquatic center offers less to a city than the other two venues, hence the lower weighted scoring of the venue.

Secondly, since the overall population of each host city differs dramatically, the number of visitors to each main stadium divided by the city's population helps to show a statistical element that does not discriminate against smaller cities. Since each city cannot be seen on the same playing field by considering statistical data alone, including the city's population into one of the factors provides an element that to some extent demonstrates the commitment to participation by the general public. Furthermore the scoring system is more even as the number of visitors is compared to the population of the city.

Third, a qualitative comparison is seen in the stadia matrix. Whether or not the venue is home to a specific professional sport provides a good perspective on whether the structure is being reused effectively. Having a constant, year in and year out schedule of events that a professional sports team offers, is a large determinant on the reuse of the stadium. Points were allotted based on whether or not a team calls the venue home, and based on how many home matches/games the team plays there in a year.

Fourth, since many of the venues are being reused in different ways, one sure way to compare them is to take into account how many yearly visitors each venue attracts. This is what was done for the Aquatics centers and Olympic stadiums.

Finally, for the Olympic Village comparison, a simple statistic of how many of the residences are occupied gives a clear answer as to how the reuse of the village has fared. A residential area's occupancy rate is a clear method that can be used for determining reuse success.

4. RESULTS & ANALYSIS

The individual adaptive reuse comparisons for the stadia, the aquatics centers, and the villages are presented. The complete matrix will provide the final scoring of the reuses, and determine how the four case studies stack up against each other.

Host City	City Population	Professional Sports Affiliation	Olympic Capacity	Current Capacity	Events	Visitors	% of Capacity / Event	Visitors / Population
Atlanta	5,650,000	Atlanta Braves	85,000	49,856	160	4,883,059	61.15%	86.43%
Sydney	4,700,000	None	110,000	83,000	90	2,449,625	32.79%	52.12%
Athens	3,475,000	Panathinaikos FC *and* AEK Athens FC	72,000	71,030	74	1,538,941	28.21%	44.29%
Beijing	16,300,000	None	91,000	80,000	57	1,460,000	32.02%	8.96%

Table 2: Usage statistics for Olympic stadia comparison

The data for the usage of the main stadium was gathered by speaking with stadium officials and visiting the physical facilities themselves. Researchers were able to visit all cities except Athens, Greece for this research. Applicable information from the website for each stadium was also used. The results of the stadium reuse are presented above in table 2.

The use of the aquatic centers for each of the Olympic venues is presented below in table 3. Accurate information for the Athens aquatic center could not be found, however from news articles that could not be confirmed, it appears that the venue is closed for public use, at the time of this research (Manfred, 2012).

Host City	Olympic Size	Current Size	Current Use	Visitors/ Year
Atlanta	14,600	1.95	Recreational facility for GT students and faculty	640,463
Sydney	15,000	4,400	Recreational and leisure area for the public	833,333
Athens	23,000	11,000	Closed to the public*	0
Beijing	17,000	6,000	Public use. Contains Asia's largest water park.	742,857

Table 3: Usage statistics for Olympic Aquatic Centers

Similar to that of the aquatics matrix, the Olympic village matrix is comprised of one factored category. Since the styles of the different villages vary from city to city, the only way to effectively compare the four villages is on their current occupancy rate. Each city's village is graded on the percentage of filled residences, albeit apartments, dormitories, houses etc. The cities, on the whole, have all done a good job of reusing their villages. Atlanta uses theirs for university housing, while the other three cities have created new communities. Atlanta, Sydney, and Beijing all have villages in which every unit is filled or privately owned. In Athens, while over 10,000 people reside in the area that was formerly the Olympic Village, information points to that fact that the community is not completely full, or accommodating to live in. No exact statistics could be found, but it seems to be true that Athens' village is less than one hundred percent filled.

Host City	Current Use	Permanent Units	Occupied Units	Occupancy Rate
Atlanta	Georgia Tech student dormitories	4,612	4,612	100%
Sydney	Newington Suburb	1,213	1,213	100%
Athens	Suburb in Athens	2,292	< 2,292	< 100%
Beijing	Suburb in Beijing	1,800	1,800	100%

Table 4: Usage statistics for Olympic Villages

Considering the usage statistics for each of the categories, the results for the comparison matrix are presented in table 5. According to the system derived, Atlanta takes the prize for the most successfully reused Olympic venues followed by Sydney, Beijing & Athens. It must be noted that even if Athens were given the full score for the Olympic village, it would still score in last place, based on the scheme used in the comparative matrix.

	Olympic StadiumOlympic Stadium					*Olympic Aquatics Center*	*Olympic Village*	
Host City	**Professional Sports Affiliations**	**Events**	**Visitors**	**% of Capacity/ Event**	**Visitors/ Population**	**Visitors/ Year**	**Occupancy Rate**	**Total Score**
Atlanta	8	8	8	8	8	10	40	**90**
Sydney	4	6	6	6	6	20	40	**88**
Athens	6	4	4	2	4	5	30	**55**
Beijing	4	2	2	4	2	15	40	**69**

Table 5: Comparison Matrix for reuse of Summer Olympic Games venues from 1996 to 2008

5. CONCLUSIONS

With the comparative analysis completed, and the matrix determined, many things stand out about the four cities. Many of the general takeaways can also be recommended practices for future host cities. The first assessment and recommendation is to think twice before submitting an Olympic bid. Nearly any city of a substantial size would like the idea of hosting an Olympic games, but the reality of it can crush a city. Cities should assess the impact that an Olympics will have on the city and its people (Cashman, 2002). An unduly awarded bid can be catastrophic. This is seen in the third case study, the 2004 summer Olympic Games, in Athens, Greece. When the IOC awarded the bid to Athens to host the 2004 Games, "the only reason was for history…The I.O.C. was so captivated by Athens' past that it overlooked the city's present"(Neumann et. al., 2004). This decision was a poor one, and one that has and will continue to negatively affect the city.

A second observation and best practice is that it is never too early to start planning for the adaptive reuse of an Olympics' venues. A city should be ready to transfer a venue into its new, post-Games life the day after the Olympic torch is snuffed out (Beard, 2011). Even more to that point, if at all possible a venue should be completed early, and offer the city a few years of use prior to the Games' opening ceremony (Johnson, 2004). Not only does this provide a financial benefit to a city, but also eases the transition from Olympic use into a venue's new life. Sydney's Olympic Park Aquatic Center shows the benefits of this. Completed six years prior to the 2000 Olympics, the center was well established before many of the 2000 Olympians were even training. At the end of the 2000 Games, the center underwent a small downsizing, and jumped immediately into its new life. The success of SOPAC shows that this strategy, if possible, is effective to guaranteeing the successful adaptive reuse of an Olympic venue.

One obvious takeaway and recommendation is to find a professional sport to move into the Olympic stadium after the Games (James, 2007). Although Sydney has fared decently well, its lack of a professional team moving into Stadium Australia will continue to limit the stadium's reuse. However, a model can be seen in Atlanta's main stadium (Sandomir, 2005). The commitment early on in the design process from the Atlanta Braves to use Atlanta's Olympic stadium is the sole reason for the unprecedented success of the venue. Athens' commitment from the two soccer clubs to use their stadium is the only factor that has allowed the stadium to be reused at all. Although still not used very often, Spyros Louis would be vacant year round without the commitment from the soccer clubs. Additionally, a commitment from a professional sports team that plays more often than others can also help. Since baseball has more games in a season than any other sport, Atlanta has been able to adaptively reuse their structure far more frequently than if the Atlanta Falcons, the city's National Football League team had taken over the stadium. The fact that Atlanta needed a professional baseball stadium as opposed to a professional American football stadium was by chance, but it has indeed aided in the reuse of Atlanta's stadium.

A final recommendation comes in the event that a city is awarded an Olympic bid, hosts the games, and is in a predicament after the Games with so many unused structures. Instead of continuing to endure large operating costs, and getting nothing in return, a city should cut its losses, and do away with the venue (Johnson, 2004). The disposal of the large investment may seem drastic, but if the venue is not seeing any results, scrapping it and using the land for a different use is the logical solution. While none of the selected venues has taken that route, many of the poorly reused structures would be better off if they were removed. For example, Athens' aquatics facilities would offer the city much more if the venue was removed and the land was rededicated for a new use.

In summary, Atlanta, Sydney, Athens, and Beijing are all well into their post-Olympics life, but the reuse strategies taken by each city have affected where they stand today. Atlanta is better off for hosting the 1996 summer Olympic Games, as the Games benefitted the city in nearly every way possible. Sydney is still in the gray area in terms of the legacy that the 2000 summer Olympic Games left on the city (Searle, 2002). Although not reused to their full potential, it still seems that the Games left the city with many useful assets and few burdens. Athens is by far the most negatively affected city. The 2004 summer Olympic Games left the city with one of the worst Olympic legacies of all times. Beijing still has not benefitted greatly from hosting the 2008 summer Olympic Games, but so fresh into the city's post-Games life, it can be turned around. If the city can find ways to bring a larger number of big-ticket events to the National Stadium, a similar study conducted in ten years may show Beijing as the most successful Olympics in terms of adaptive reuse.

The Olympics are an incredible event that brings the entire world together for two and a half weeks every four years in celebration of human accomplishment, not just of the athletes but of the host cities and countries as well. The competitions, events, and records broken are a thrill for every human to witness. However the legacy that the Games will leave on the host city is something that only that city and its residents will feel. The world can join in and help to make the seventeen-day Olympic Games a success, but the Olympic legacy that is left, is for the individual host city to determine (James, 2007).

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PROBABILISTIC ASSESSMENT OF THE EFFECT OF CLIMATE CHANGE ON THE CARBONATION OF CONCRETE STRUCTURES IN THE CARPATHIAN BASIN

Árpád Rózsás
Budapest University of Technology and Economics, Budapest, Hungary, rozsas.bme@gmail.com

Nauzika Kovács
Budapest University of Technology and Economics, Budapest, Hungary, nauzika@vbt.bme.hu

Abstract

Due to mainly human activity in the following decades we are facing increasing mean global temperature and rising CO_2 concentration. This paper investigates the effect of these changing environmental parameters on the durability of concrete structures. We restrict our attention to the examination of carbonation process and to environmental data applicable for the Carpathian Basin. The carbonation model is based on the internationally recognized CEB-*fib* model. The climatic parameters are considered through 6 climate change scenarios according to the recommendation of the Intergovernmental Panel on Climate Change. Full probabilistic approach utilizing Monte Carlo simulation technique is used to analyze the reliability of currently applied concrete covers against depassivation of reinforcement. A numerical method is proposed to efficiently take into account the time-varying atmospheric CO_2 concentration. This method is used to assess the error of widely applied constant CO_2 level approximation. The calculations indicate that climate change could have a significant effect; the carbonation depth may increase by 15-20% until the end of this century compared to year 2000 as a reference. The risk of depassivation of reinforcement could increase by 60% over time to 2100. The results suggest that the effect of climate change should be considered in design codes.

Keywords: climate change, concrete carbonation, Eurocode, Monte Carlo simulation, reliability.

1. INTRODUCTION

Climate change is an ongoing process which already affects our life and may lead to devastating effects in the future [IPCC, 2007]. It is estimated that in 2012 climate change has contributed to 1-2% GDP loss on a global scale [DARA, 2012]. This paper deals with a process which in the following decades could deepen this burden, i.e. carbonation of concrete which ultimately may lead to the failure of structures. This phenomenon has great importance since buildings and civil infrastructure comprise about 80% of the national wealth of developed countries [Sarja, 2005] and the majority of these are made of reinforced concrete which is the most widely used construction material on Earth. The designers of these structures bear great responsibility since their creations will be used by future generations and have significant effects on our natural and built environment. Therefore, decisions made today could have harsh effects within 50-100 years which are the typical design lives of buildings and bridges.

Previous studies showed that climate change considerably accelerates the carbonation process [Yoon *et al.*, 2007; Stewart *et al.*, 2011; Talukdar *et al.*, 2012] and could have significant effects on the durability of concrete structures [Stewart *et al.*, 2012; Talukdar and Banthia, 2013]. These studies are dealt with the Australian continent and with major cities around the world. There is a lack of analysis for Continental Europe and for the region of the Carpathian Basin. To realistically assess the effect of climate change reliability analysis has to be carried out. Previous probabilistic studies did not take into account the time-varying CO_2 concentration and typically used average values; the associated degree of error is not known. Moreover, the current standardized specifications are based on historical data not on full probabilistic analysis and do not take into account the effect of climate change.

Based on the above considerations and unanswered questions the main goals of this paper are the followings: (i) Evaluation the effect of climate change on the carbonation of concrete structures in the Carpathian Basin and (ii) the investigation the increase in risk of depassivation considering the provisions of Eurocode. (iii) Quantitative assessment of the time-varying CO_2 level on the carbonation process. For the analysis carbonation model coupled with global climate change scenarios is used and full probabilistic reliability analysis is applied to calculate the effect of uncertainties.

2. MODEL DESCRIPTION

2.1. Carbonation Model

The carbonation model recommended by CEB-*fib* Model Code for Service Life Design (MC SLD) is used which has relatively broad internationally acceptance [CEB-*fib*, 2006]. A further advantage of this model is that the stochastic properties of the parameters are also provided. The applied carbonation model is based on Fick's laws of diffusion; these are widely used to describe the CO_2 or chloride ion transportation in concrete. Fick's second law describes the concentration change in time and expresses the mass conservation, Eq. (1):

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} \tag{1}$$

The solution of this parabolic partial differential equation (pde) in one dimension with constant concentration at the air-concrete boundary is given by Eq. (2).

$$C(x,t) = C_0 \cdot erfc\left(\frac{x}{2 \cdot \sqrt{D \cdot t}}\right) \tag{2}$$

Where x is the distance from the boundary, C_0 is the constant CO_2 level ($C(x=0,t) = C_0$), D is the diffusion coefficient, t is time and *erfc* is the complementary error function. Using Eq. (2) the carbonation front in concrete can be expressed in the following form:

$$x_c(t) = \sqrt{2 \cdot D \cdot t} \tag{3}$$

The CEB-*fib* carbonation model has the same square root of time form (Eq. (4)) as the above solution with additional factors to take into account the effect of environmental conditions, period of curing, etc. [CEB-*fib*, 2006].

$$x_c(t) = \sqrt{2 \cdot k_e \cdot k_c \cdot R_{NAC}^{-1} \cdot C_S}\sqrt{t} \cdot W(t) \tag{4}$$

where:
k_e environmental function [-], Eq. (5);
k_c execution parameter [-], Eq. (6);
R_{NAC}^{-1} inverse carbonation resistance $\left[\frac{m^2/yr}{kg/m^3}\right]$, Eq. (7);
C_S CO_2 concentration of atmosphere [kg/m^3], Eq. (8);
t time [yr];
$W(t)$ weather function [-], Eq. (9).

$$k_e = \left[\frac{1-(RH_{real})^{f_e}}{1-(RH_{ref})^{f_e}}\right]^{g_e} \quad (5), \qquad k_c = \left(\frac{t_c}{7}\right)^{b_c} \quad (6), \qquad R_{NAC}^{-1} = k_t \cdot R_{ACC}^{-1} + \varepsilon_t \quad (7),$$

$$C_S = C_{S,atm} + C_{S,emi} \quad (8), \qquad W(t) = \left(\frac{t_0}{t}\right)^{\frac{(p_{SR} \cdot ToW)^{b_w}}{2}} \quad (9)$$

The names and values of these variables are summarized in *Section 3, Table 1*. Previous studies demonstrated that urban environments have an elevated CO_2 level compared to rural areas [Stewart *et al.*, 2002]. Since most reinforced concrete structures are located in urban areas and the most unfavorable situation should be considered the $C_{S,emi}$ term is taken as 15% of atmospheric concentration ($C_{S,atm}$) with 0.15 coefficient of variation (COV) [Stewart *et al.*, 2011]. The main drawback of Eq. (4) is that it provides a point-in-time estimation and cannot take into account the time-varying manner of CO_2 concentration which is the most important parameter in the diffusion process [Stewart *et al.*, 2011]. To circumvent this problem the following numerical procedure is proposed which takes advantage of the particular character of governing pde and boundary conditions. Since the differential equation is linear the principle of superposition is valid and a mathematically sound approach is to solve the equation with the sum of basic solutions for constant concentration (Eq. (10), *Figure 1*). The advantage of this approach is that the previously conducted researches and experiments which are based on constant CO_2 concentration can be directly applied.

$$C_{tot}(x, t_{[0,\infty[}) = \sum_{i=1}^{n} C_{0,i} \cdot erfc\left(\frac{x}{2 \cdot \sqrt{D_i \cdot t_{[t_i,\infty[}}} \right) \tag{10}$$

The above formulation makes it possible to consider time-varying diffusion coefficient as well. To determine the carbonation depth a CO_2 threshold value is needed at which the pH of concrete drops below about 9 and depassivation happens. This threshold value is determined by using the known, experimentally calibrated constant CO_2 level solutions.

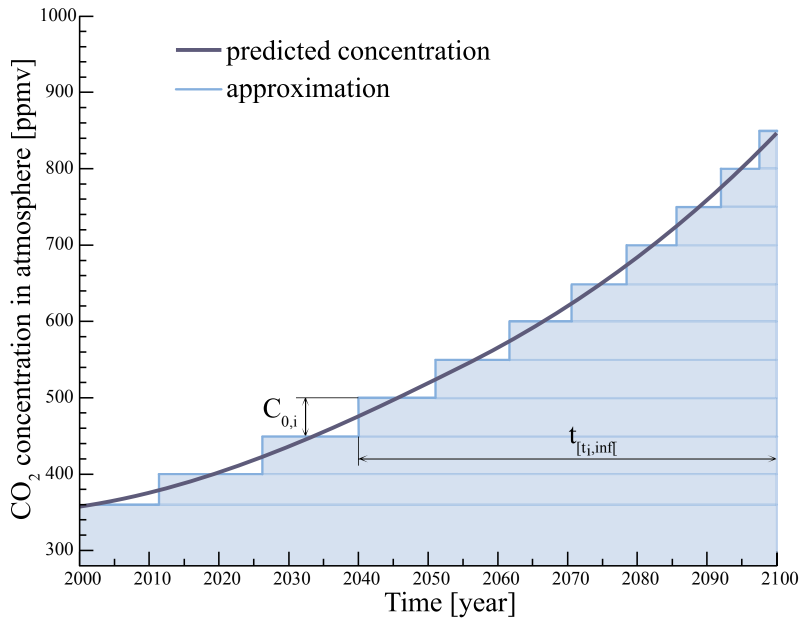

Figure 1: Graphical representation of the applied numerical procedure.

The method is verified against examples with constant CO_2 concentration published in CEB-*fib* MC SLD. Moreover, the time-varying case is checked by solving the differential equation by MATLAB's built-in pde solver (this is a more general and robust solver therefore requires considerably higher computational time). The calculations showed that the described method converges quickly to the exact solution and they are used to tune the parameters, i.e. the discretization of time and depth space, to get efficient algorithm with desired accuracy.

It should be noted that the used carbonation resistances are determined by accelerated carbonation tests with unloaded and completely sound specimens. The effect of real in-service conditions is not yet comprehensively analyzed, but it is clear that cracks lower the durability.

2.2. Climate Change Predictions

Following the recommendation of the Intergovernmental Panel on Climate Change (IPCC) multiple scenarios are selected [IPCC, 2007]; one scenario from every SRES (Special Report on Emission Scenarios) family which represent a wide range of possible outcomes. These describe economic (A1, A2) and environmental (B1, B2) focused future developments with local (A2, B2) or global (A1, B1) orientations. The three groups within the A1 family are characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Additionally, a reference concentration level (reference 2000) is chosen which represent the CO_2 level in 2000 on which the current experiences and standards are roughly based. The predicted global atmospheric CO_2 concentrations corresponding to the selected scenarios are depicted in *Figure 2*. The shaded areas show the ±σ range considering lower, medium and higher carbon cycle feedbacks.

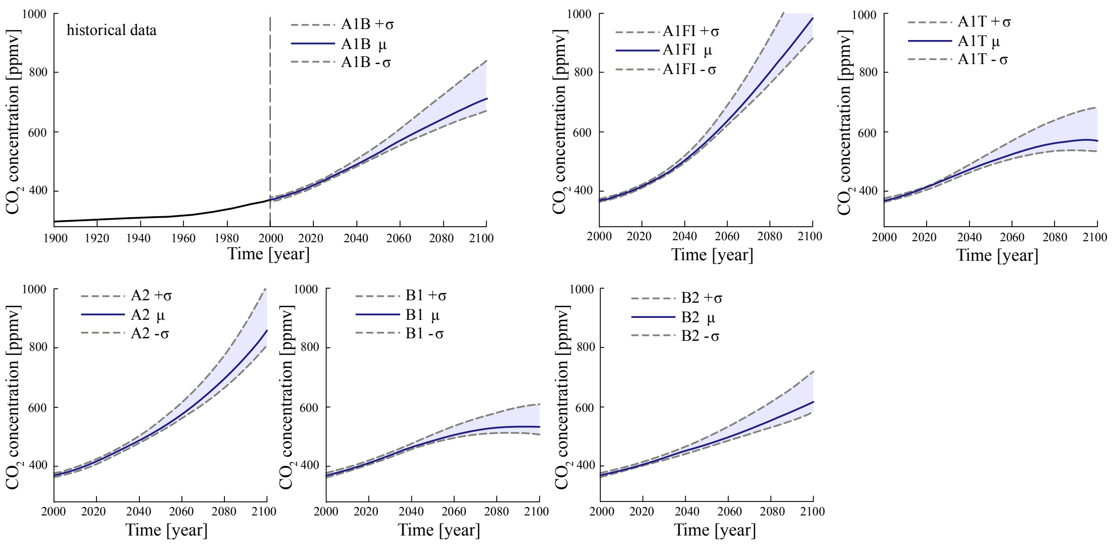

Figure 2: CO_2 concentration for various SRES climate change scenarios [IPCC, 2007].

Due to the limited available data on the actual density functions of CO_2 concentration normal distribution is fitted to the mean and +σ upper quantile value. Other environmental variables are approximated from earlier measured data of Hungarian meteorological stations. This is justified by the fact that the expected change to 2100 in the average value of relative humidity and precipitation is not significant [Bartholy *et al.*, 2011].

3. RELIABILITY ANALYSIS

The uncertainties of the model variables are considered through Level III probabilistic analysis, where all variables are taken into account by their exact probability density functions and the exact probability of failure is determined [JCSS, 2000]. Here the exact means that the exact solution of the mathematically formulated problem is approached by numerical techniques. The limit state function (g) for the depassivation of reinforcement is expressed in Eq. (11).

$$g = (a - 5mm) - x_c(t) \tag{11}$$

Where a is the minimum concrete cover which can be calculated by reducing the nominal cover (a_{nom}) with a safety margin (Δa), Eq. (12).

$$a = a_{nom} - \Delta a \tag{12}$$

The safety margin for typical structures is 10mm [EN-2, 2004; CEB-*fib*, 2006], this value is adopted in this study. The additional 5mm reduction reflects the experimental fact that the depassivation of reinforcement happens when the carbonation front reaches 5mm vicinity of the rebar [Yoon *et al.*, 2007].

The introduced method for determination of carbonation depth only requires matrix operations, thus the evaluation of the limit state function is not computationally intensive. Moreover, the chosen probability of failure corresponding to depassivation is around 0.1. Therefore, significantly fewer evaluations are required to obtain low-variance solution than in case of ultimate limit states. Based on the above considerations crude Monte Carlo method is chosen to carry out the Level III reliability analysis. *Table 1* summarizes the variables with their probabilistic properties.

Table 1: Stochastic properties of model variables.

	Distribution	Mean	COV	Reference
Relative humidity of carbonated layer (RH_{real}), [-]	Beta	0.70	0.125	[CEB-*fib*, 2006]
Reference relative humidity (RH_{ref}), [-]	Constant	0.65	0	[CEB-*fib*, 2006]
Exponent (g_e), [-]	Constant	2.50	0	[CEB-*fib*, 2006]
Exponent (f_e), [-]	Constant	5.00	0	[CEB-*fib*, 2006]
Regression exponent (b_c), [-]	Normal	-0.567	0.042	[CEB-*fib*, 2006]
Period of curing (t_c), [day]	Constant	2.00	0	
Inverse carbonation resistance (R_{NAC}^{-1}), [$mm^2/yr/(kg/m^3)$]	Normal	varying	varying	[CEB-*fib*, 2006]
Regression parameter (k_t), [-]	Normal	1.25	0.28	[CEB-*fib*, 2006]
Error term (ε_{tm}), [$mm^2/yr/(kg/m^3)$]	Normal	315.50	0.152	[CEB-*fib*, 2006]
Equivalent water cement ratio, [-]	Constant	0.60	0	[CEN, 2002]
CO_2 concentration of atmosphere (C_{Satm}), [ppmv]	Normal	varying	varying	[IPCC, 2007]
CO_2 concentration due to emission (C_{Semi}), [ppmv]	Normal	$0.15*C_{S,atm}$	0.15	[Stewart *et al.*, 2011]
Probability of driving rain (p_{SR}), [-]	Constant	0.10	0	
Exponent of regression (b_w), [-]	Normal	0.446	0.365	[[CEB-*fib*, 2006]
Time of reference (t_0), [yr]	Constant	0.0767	0	[CEB-*fib*, 2006]
Time of wetness (ToW), [-]	Constant	0.20	0	
Nominal concrete cover (a), [mm]	Weibull	varying	$8/\mu_a$	[CEB-*fib*, 2006]

The correctness of Monte Carlo simulation is confirmed by the examples available in CEB-*fib* MC SLD. The calculations are completed using data predicted for Hungary, but the presented method can be used irrespectively of geographic location.

4. ANALYSIS RESULTS

4.1. Assessment the error of constant CO_2 approximation

The above presented carbonation model coupled with climate change predictions is used to estimate the error of – in previous studies applied – constant CO_2 level. Hereinafter in all calculations the beginning of carbonation is year 2000. Two different constant approximations are examined. One with a single average CO_2 level over the whole considered time domain (I) and one with time-varying average CO_2 level (II). The latter implies that the average concentration is calculated for every time instant by taking the average of preceding concentrations; this approach was applied by Stewart *et al*. (2011). Comparison the mean values of approximation (I) to exact time-varying solution for CEM I 42.5R cement is shown in *Figure 3*.

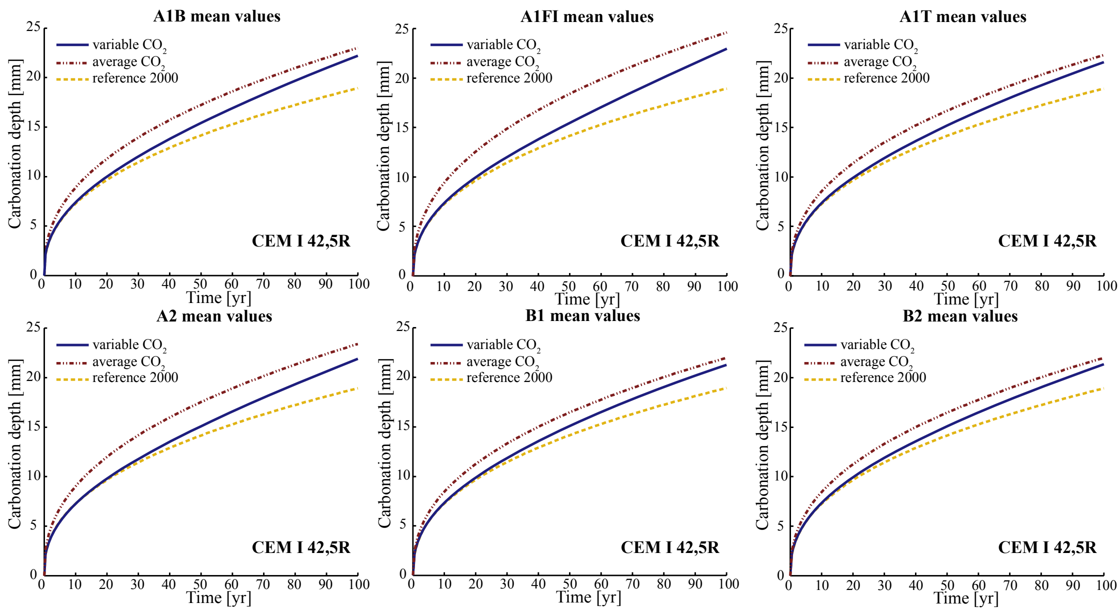

Figure 3: Mean value of carbonation depth in time for time-varying, averaged and reference CO_2 concentration.

For various climate change scenarios the comparison of reference, varying average (approximation II) and exact time-varying solutions are illustrated in *Figure 4*.

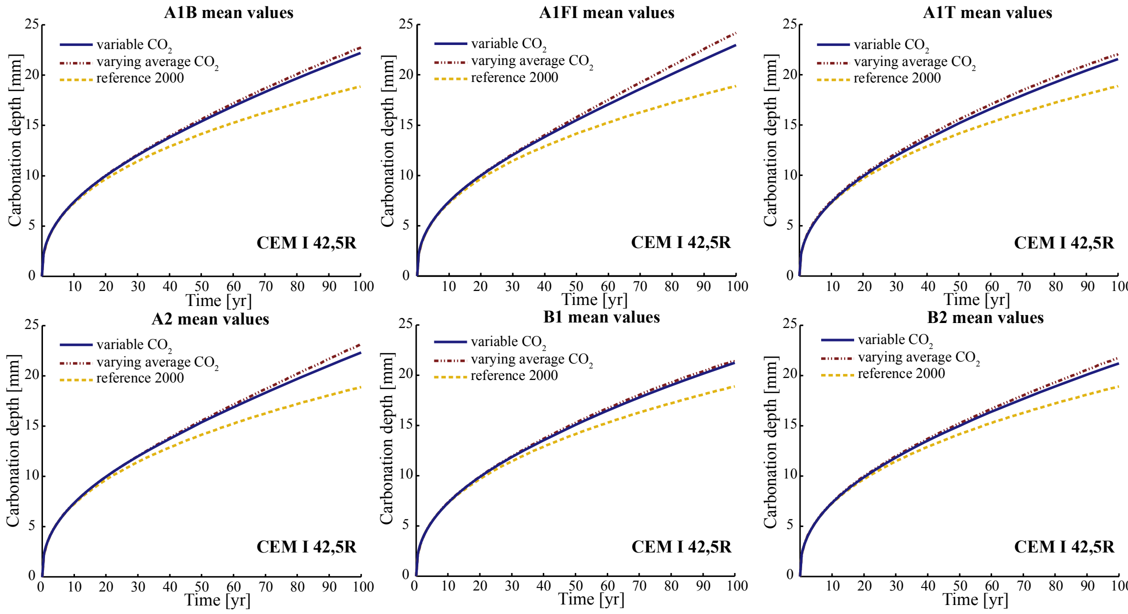

Figure 4: Mean value of carbonation depth in time for time-varying, varying average and reference CO_2 concentration.

The calculations are completed with CEM I 42.5R +FA and CEM III\B 42.5 cement types as well, the results follow very similar trend as shown in *Figure 4*. The upper row of *Figure 5* shows the error of varying average approximation for the three cement types. Both varying average and exact time-varying solutions contain the effect of initial CO_2 level which distorts the comparison and lessen the difference between the two approaches. Thus, the difference of the two approaches is calculated in respect of increase over the reference curve; these data are visualized in the lower row of *Figure 5*.

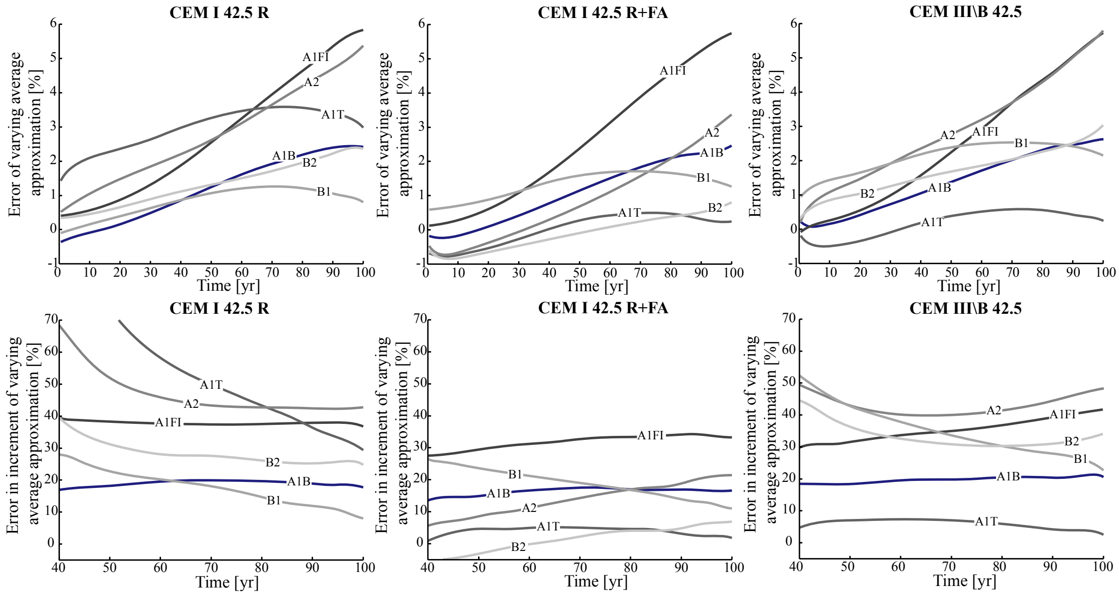

Figure 5: Error of varying average approximation in absolute and increment terms.

4.2. Examination of Eurocode's durability specifications

Since the current specifications are not taking into account the effect of climate change and the recommendations "are not based on physically and chemically correct models but more on practical (sometimes bad) experience. In the future currently applied rules urgently have to be calibrated against the full probabilistic approach [CEB-*fib*, 2006]." Following this recommendation the reliability of durability specifications of Eurocode in the light of climate change is examined. As an illustrative example a reinforced concrete structure with 100 year service life (built in 2000) is analyzed with the above presented approach. It assumed to belong to structural class S6 and exposure class XC2, the corresponding recommended minimum concrete cover is 35mm. Three different cement types are studied (CEM I 42.5R, CEM I 42.5R+FA, CEM III\B 42.5); other parameters are listed in *Table 1*. The probability of depassivation and the increase in probability of depassivation is illustrated in *Figure 6* for various climate change scenarios. In the lower row figures (*Figure 6*) the initial 30 years period is not illustrated because the results show large scatter. Higher simulation number would be required to get reliable results in that region with low probability of failure. It should be noted that in the first 30 years the effect of climate change is low thus not particularly interesting for the current study. In this illustrative example, the time-varying average approach for CEM I 42.5R, CEM I 42.5R+FA and CEM III\B 42.5 overestimates the probability of depassivation - compared to the mathematically sound solution presented in *Section 2.1* - by maximum 13%, 18% and 3,1% respectively. The maximum is in every case corresponding to A1FI scenario, for the other predictions the error is slightly lower.

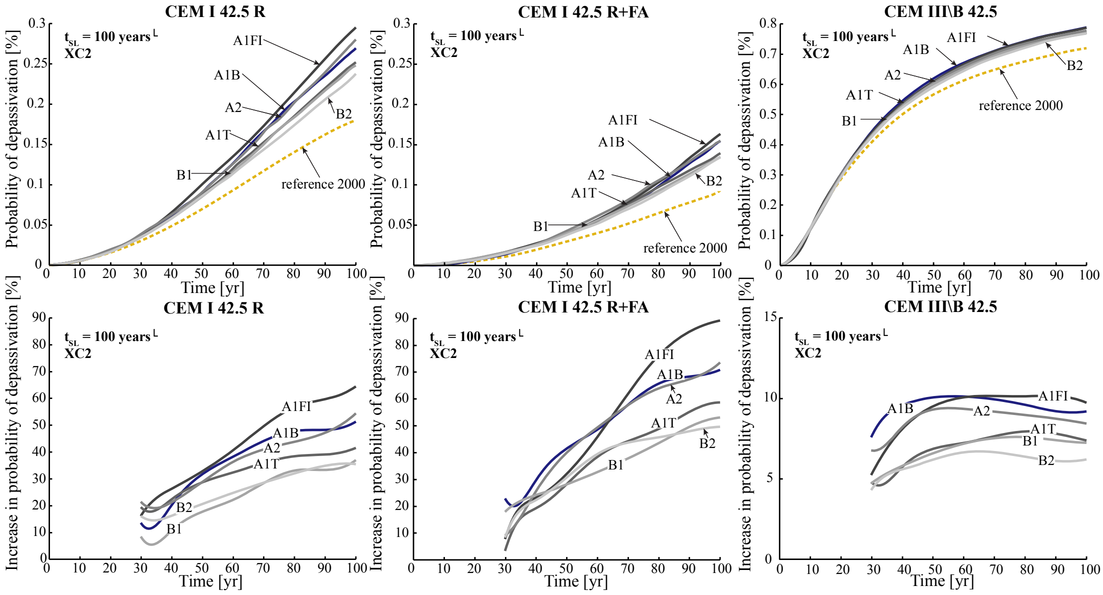

Figure 6: Probability of depassivation and increase in risk due to climate change.

The significant difference between the results of CEM I and CEM III is explained by the about eight times higher carbonation resistance of CEM I. It should be noted that CEM I and II type cements are the most widely used cement types and the high early strength CEM III type is rarely used. The European concrete specification (EN-206-1) does not differentiate between cement types regarding exposure classes and covers [CEN, 2000]. Although the experimentally determined diffusion coefficients and the numerical results show significant difference based on cement type (*Figure 6.*). It may be worthwhile to prescribe the applicable cement types as well in the durability requirements to avoid low carbonation resistant cements such as CEM III\B.

5. DISCUSSION OF RESULTS AND CONCLUSIONS

The obtained results and trends are in good agreement with the data available in the literature, the calculations confirmed many findings of previous studies, e.g. for structures built in 2000 the effect of climate change in the first 25-35 years is low [Talukdar and Banthia, 2013].

Based on the full probabilistic reliability analysis of concrete carbonation, using multiple climate change scenarios, the following conclusions can be made for the Carpathian basin region: (i) Firstly, climate change has clearly significant effect on the carbonation of concrete, this could be manifested in even a 21 % increase in carbonation depth to the end of the century compared to 2000 year reference. To 2050 and 2100 the average carbonation depth is expected to increase by approximately 7% and 15% respectively. (ii) A numerical procedure is proposed to directly take into account the variability of CO_2 concentration in time. The analyses showed that in the previous studies applied varying average CO_2 level yields to maximum 6% error in respect of carbonation depth and maximum 18% in probability of depassivation. The single value average approximation gives even worse prediction. It should be emphasized that these approximations are always overestimate the carbonation depth. (iii) Climate change scenarios have considerable effect on the degree of change but their predicted trend is unanimously increasing in respect of carbonation depth and the risk of depassivation. (iv) New structures built in 2000 and designed according to Eurocode are expected to be affected slightly by climate change in the first 25-35 years. Nonetheless, to the end of the century the increase in the risk of depassivation due to climate change for CEM I 42.5R and CEM I 42.5 R+FA could increase by 35-65% and 50-90% respectively. Based on the findings and literature data the revision of current standardized specifications regarding concrete durability in the light of climate change is needed.

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CONCEPTUAL FRAMEWORK FOR SITE SAFETY MONITORING USING RFID AND BIM

Anoop Sattineni
Auburn University, Auburn, AL, USA, sattian@auburn.edu

Jason Underwood
University Salford, Salford, UK, J.Underwood@edu.salford.ac.uk

Farzad Khosrowshahi
Leeds Metropolitan University, Leeds, UK, F.Khosrowshahi@leedsmet.ac.uk

Abstract

Supervision of construction workers on a site is crucial to ensure construction worker safety, to maintain the quality of work performed and to maintain acceptable levels of productivity. The act of supervision itself requires the site superintendent to physically monitor workers in an environment that is constantly changing throughout the construction phase. This is not always an easy task on a medium to large multi-storied building site with several trades working simultaneously on multiple floors. The construction site typically consists of skilled and unskilled crews of workers involved in the various crafts. There exists a need for construction superintendents to know the location of construction workers within a site. Academicians and industry professionals have demonstrated the use of Radio Frequency Identification (RFID) Tags in construction applications in the past few years. RFID tags have successfully been used to track construction materials, equipment and personnel. Studies indicate that the use of RFID tags in construction improves the overall process of construction. Building information modeling (BIM) technology is emerging as the industry standard in the architecture, engineering and construction (AEC) sector. BIM is being used as a comprehensive design, management, visualization, communication and facility maintenance and management tool. This paper presents a decision support framework for site supervision based on monitoring construction workers by combining RFID technology with BIM technology. The real-time movement of workers is tracked by the RFID tags and represented in a virtual environment aided by BIM. A conceptual decision support framework developed by interviewing construction superintendents is presented. Scenarios for implementing the framework are presented. It is hypothesized that this combination of real time movement of workers in a virtual environment will improve construction worker supervision.

Keywords: Conceptual Framework, Safety, Supervision, BIM, RFID

1. INTRODUCTION

Construction site supervisors play a crucial role in maintaining a safe work environment. Safety on a construction project is driven by several issues such as site layout, site location, construction schedule, safety training provided to workers, safety monitoring on the site, worker morale, culture & attitudes towards safety etc. However supervision also plays a key role in maintaining safety within the construction site (Aksorn and Hadikusumo, 2008, p. 715). The lack of proper supervision can be attributed as one of the root causes for adverse effects on safety performance (Tam et al., 2004, p. 573). This research has found that apart from maintaining a safe work environment, the supervisor is responsible for production, materials, schedule, coordination and managing subcontractors on site. It is not possible for the supervisor to keep an eye on workers at all times during a typical day on the construction site. This research found that knowing the location of construction workers within the site is information the supervisor can use to make critical decisions in maintaining a safe construction site. Advancements in computing technologies in society and their adoption within the construction industry have resulted in several improvements in maintaining a safe construction site (Li et al., 2012, p. 498; Li and Liu, 2012, p. 112). Building Information Models (BIM) represent a seismic shift in the nature of how the architecture, engineering and construction industries (AEC) work and interact with one another. In the last few years BIM has been increasingly adopted in the construction industry and is currently being used in a number of ways to improve the construction process (Azhar, Salman et al., 2008, p. 9). The use of BIM as a visualization tool in and of itself has been shown to have great benefits to the AEC industries (Yan et al., 2011, p. 446; Gu and London, 2010, p. 988). Meanwhile tracking technologies such as RFID have been demonstrated to contribute to the construction process by allowing materials, tools and equipment to be tracked electronically (Demiralp et al., 2012, p. 128; Grau et al., 2012, p. 43; Song and Eldin, 2012, p. 32).

This research aims to create a framework for monitoring the location of US construction workers on site by combining RFID and BIM technologies. The site supervisor can use this combination to make critical decisions related to safety. By enabling the site supervisor to locate personnel within the site, it also provides the site supervisor an additional measure to ensure that workers are not present in areas where they are not trained to be and that workers are in the locations where they are assigned.

A conceptual framework was developed to combine BIM and RFID technologies to track construction workers on site. This conceptual framework was created from the qualitative data collected by interviewing nineteen construction site supervisors in the United States.

2. BACKGROUND

2.1. Construction Safety

There were an average of 1121 fatalities that occurred annually in the US construction industry between 1992 and 2010. During the same time period the construction industry averaged for approximately 19% of all work place related fatalities (Bureau of Labor Statistics, n.d.) making it one of the most dangerous professions in the US. Construction site safety is a very complex yet expensive issue. Lapses in safety in the construction industry are linked to major economic losses (Cheng et al., 2011, p. 1173). On the other hand, a successful safety record contributes to higher morale, profitability, turnover and margins. A successful safety record can serve as a sustainable competitive advantage (Rechenthin, 2004, p. 307). To understand the issue of safety in the construction industry it is relevant to understand the various reasons accidents have been known to occur in the construction industry.

The working conditions on a construction site are constantly changing and pose an inherent safety risk (Chae and Yoshida, 2010, p. 368). This unpredictable nature of construction tasks increases the risk of workers being exposed to a hazard or hazardous condition (Mitropoulos et al., 2005, p. 822). Construction workers often work with specific deadlines on tasks and are frequently working with their bodies in awkward positions (Gillen et al., 2002, p. 34). The pressures of keeping a construction job on schedule have been a known cause for the occurrence of accidents (Schneider and Check, 2010, p. 283). Optimism bias is a concept wherein a subject feels that negative things are less likely to happen to him/her than the average person. Optimism bias exists among construction workers with regards to their personal safety on site and can lead to complacency when implementing safety management plans on the construction work site (Caponecchia and Sheils, 2011, p. 253). Overcrowded workplaces in construction can contribute to unsafe construction environments (Gittleman et al., 2010, p. 277). The cost and time for implementing proper protection mechanisms may lead to complacency and accidents, especially in smaller construction firms (Holmes et al., 1999, p. 260). Studies also indicate that smaller sub-contractors may not have full-fledged safety training programs for their workers (Goldenhar et al., 2001, p. 251). Language barriers within the workers exist in the US construction industry due to the presence of about 2.2 million Hispanic workers on construction sites (Gittleman et al., 2010, p. 278)(Evia, 2011, p. 453). These language issues can cause potential communication gaps resulting in safety incidents. It is commonplace in the construction industry for workers to do overtime. Working overtime can have adverse effects for the health and safety of the workers (Goldenhar et al., 2003, p. 215).

2.2. Field Supervision in Construction

The role of monitoring is an important aspect of maintaining a safe work environment (Loosemore, 1998, p. 51). The role of the foreman in monitoring workers on an industrial site is important to ensure a safe work environment (Flin and Yule, 2004, ii47). Productivity of construction workers is directly related to the profitability of a construction project (Motwani et al., 1995, p. 18). Construction worker supervision plays an important role in improving construction productivity and quality. The longitudinal study done by Kines et al. (2010, p. 399) demonstrated that construction superintendents were coached to improve site safety conditions by 7% to 12%. Similarly importance for the role of the site foreman has not changed over the years, as shown by Fung et al. (2005, p. 504), Saliminen & Saari (1995, p. 263) and Lemna et al. (Lemna et al., 1986, p. 210). Studies have also revealed that jobsite supervision was rated as the most important, among a list of issues to improve productivity on the construction site (Arditi, 1985, p. 8). Studies have been conducted to monitor construction workers using video cameras using identification technologies (Teizer and Vela, 2009, 452). However these studies also indicate several problems with tracking construction workers using video camera technologies, partly since it is based on line of sight technology and also since algorithms for automatic recognition of personnel are not fully developed yet (Yang et al., 2010, p. 374).

2.3. Use of RFID in Construction:

Academicians and researchers have increasingly advocated the use of RFID technology in construction processes for at least the past decade (Jaseiskis and Ei-Misalami, 2003, p. 688; Lu et al., 2011, p. 108). The technology has been successfully used in construction for tool tracking (Goodrum et al., 2006, p. 292), material tracking (Ren et al., 2011, p. 206), managing construction documents (Elghamrawy and Boukamp, 2010, p. 1065) and supply chain management of construction materials (Wang et al., 2007, p. 388). Researchers Navon (2005, p. 475) and associates have demonstrated (Navon and Sacks, 2007, p. 482) the need for automated project performance control on construction sites and suggested the use of RFID (Navon and Goldschmidt, 2003, p. 197) as means to achieve the same. Wang demonstrated that it was possible to enhance the processes of inspections in construction by means of RFID technology (Wang, 2008, p. 478). RFID tags were also used to demonstrate material management of temporary structural members (Oyama and Yabuki, 2007, p. 703), managing materials in high rise construction using RFID enabled lift cars (Cho et al., 2011, p. 411) and in the production of precast members in a component factory (Yin et al., 2009, p. 689). Researchers Haas, Song, Caladas, Grau and Razavi have done substantial work in validating the use of RFID technology for construction applications. They have demonstrated the use of RFID tags to track on-site materials (Song et al., 2007, p. 376) and automating the supply chain of fabricated pipe spools (Song et al., 2006, p. 176). In one study they showed that the time required for tracking materials using RFID technology was reduced by a ratio of 8 to 1, resulting in a productivity increase of 4.2% (Grau et al., 2009, p. 910). Several methods for locating RFID tags were proposed by them, some of which might have some potential uses for the purpose of this study(Razavi and Haas, 2010, p. 1046). Another method for locating RFID tags, called the 'Centroid' method, was proposed on an industrial project by Grau and Caldas, which seemed to improve the precision of locating RFID, compared to the proximity method developed by Song & Haas (Song et al., 2007, p. 369). Location tracking has been shown as an important aspect in delivering context specific information to users in construction (Behzadan et al., 2008, p. 737). While this has been successfully developed and utilized in an outdoors environment, location tracking in an indoor environment while construction is taking place can be difficult (Behzadan et al., 2008, p. 738). The research done by Khoury and Kamat (2009, p. 456) shows that the precise location of people or objects in an indoor environment requires line of sight based systems. However the work done by Ko (2010, p. 593) shows that RFID tags can be located with increasing efficiency in a 3D space using multiple localization methods.

2.4. Building Information Modeling in Construction

Two-dimensional (2D) drawings to represent buildings were the norm in the AEC industries until a few years ago. Several 2D drawings, predominantly produced using lines, were required to represent an object in 3D, resulting in inconsistencies within the various views. Even before the use of BIM, researchers have been experimenting with object-based models for buildings (Papamichael et al., 1997, p. 341). BIM technology is based on representing building elements using intelligent objects. These objects in a BIM model can be real objects with 3D characteristics such as beams, walls, equipment etc., as well as abstract objects such as spaces, rooms and areas. These objects are often referred to as parametric objects, as they are built with certain inherent rules, such as requiring a door to be imbedded in a wall and move with the wall (Eastman et al., 2011, p. 42). BIM technology improves the overall quality of design, provides better performing buildings, and requires fewer change orders during construction (Azhar et al., 2008, p. 9). BIM allows the contractor to optimize the schedule and cost of the project while also providing for an efficient handover of buildings to owners for operations and maintenance (Azhar et al. 2008, p. 9). While all the benefits have been empirically accepted as true, the determination of a return on investment in BIM has turned out to be much more complicated (Barlish and Sullivan, 2012, p. 149).

2.5. Combining RFID with BIM for Construction Safety

The methods for combing RFID and BIM technologies are presented in figure 1. Active RFID tags are proposed in this research along with RFID readers, which may be installed at pre-determined locations on the jobsite. Each signal from RFID tags will need to be stored in a database. The Application Programming Interface (API) for the RFID hardware is to be used to transfer information about the tags into a database. The information will include the tag identification number, time the signal was received and the Received Signal Strength Indication (RSSI). The information will be further processed using established methods for locating RFID tags to determine the approximate location for each tag (Grau et al., 2009; Razavi & Haas, 2010; Ergen et al., 2007; Song et al., 2007).

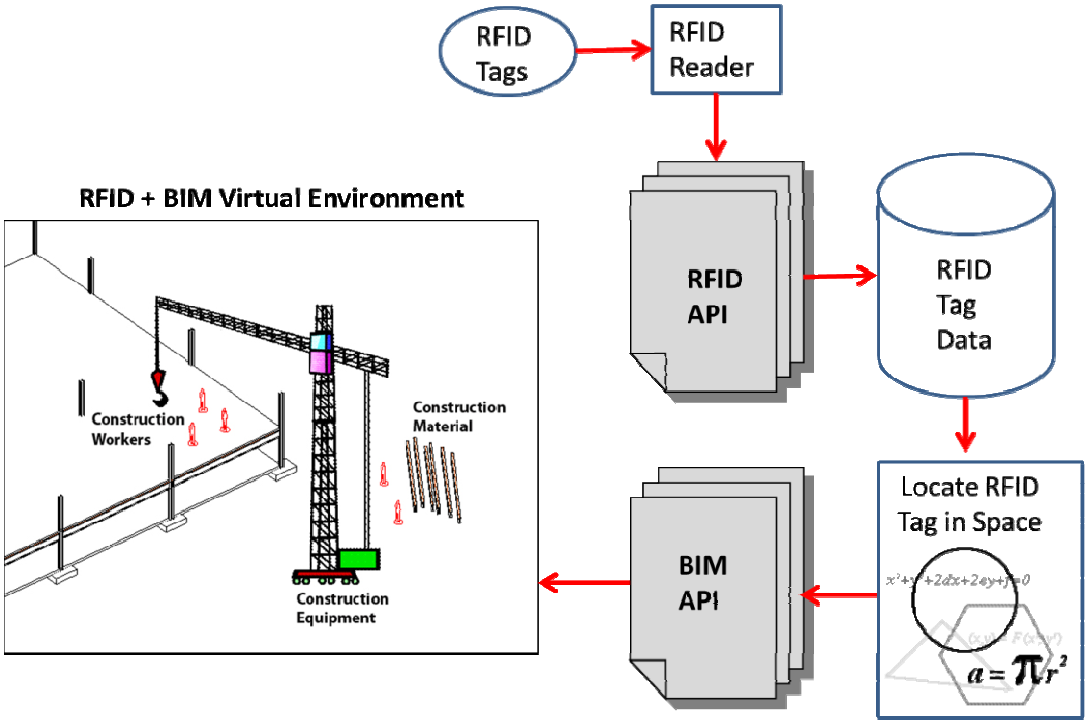

Figure 1. Hardware and software strategy for combining RFID technology with BIM technology into a virtual prototype.

3. METHODOLOGY, DATA COLLECTION AND ANALYSIS

A phenomenological philosophy implicitly admits that superintendents' perspective regarding safety is shaped by his or her experiences and beliefs rather than explicit, objective reality outside of these perceptions (Fellows and Liu, 2009, p. 70). By using a phenomenological approach this research aims to understand superintendents' perspective of site safety, their approach to various situations on site and their perspective on automating certain aspects of site safety practices. Hence, for the purpose of this research, a phenomenological philosophy is adopted. The strategy for this research must validate that construction site safety supervision can be improved by creating a framework for monitoring the movement of workers on a jobsite, using RFID and BIM technologies. Every construction jobsite is unique due its geography, local culture, size, budget, schedule, location, type of project etc. It is also not feasible to conduct an industry wide research of an exploratory innovation. Therefore the use of a qualitative research design was used for this study.

The researcher had informal discussions with two retired construction superintendents about the study. In part this was done as a pilot study for the research. Based on feedback from these discussions and literature review, a final questionnaire was created with 10 questions. The interview questionnaire was aimed at understanding the aggregate role of the construction superintendent. Several questions were specifically targeted on site safety issues from a construction superintendent's perspective. Questions targeting the location of workers within the construction site and its relationship to site safety were created.

The data collection methods for this research included, semi structured and structured interviews with site superintendents. Use of interviews to collect data is an acceptable in social research and the sample size is also generally acknowledged to be small (Denscombe, 2007, p. 111). Initially twenty construction site superintendents were contacted for conducting interviews. The number twenty was based on the study conducted by Guest et al. (2006, p. 59) who have shown that data saturation occurred after twelve interviews in qualitative studies. Nineteen construction site superintendents were interviewed in the way of data collection. Each interview was conducted at a time and place of convenience of the interviewee. Each interview lasted approximately 35 minutes to an hour.

Atlas.Ti, a qualitative research data analysis software tool was purchased and used to analyze the interview data. The transcribed interviews as well as the audio recordings were imported into the software. Answers for each question from all the interviews were categorized into ten separate documents and were also imported into the software. The analysis process consisted of first reading all the answers for each individual question. The researcher then created several codes for the data using the 'Open Coding' process, which is an acceptable method to report qualitative data from interviews (Weston et al., 2001, p. 381); (DeCuir-Gunby et al., 2011, p. 138).

4. RESULTS

The data collected in the interviews was used to develop a conceptual framework for construction safety monitoring based on combining RFID and BIM technologies. This process involved counting repeating codes in trying to identify areas / situations that allowed the proposed solution to be used in implementing job site safety (IAR, University of Texas, 2007). Eighteen of the nineteen superintendents thought that the proposed solution would be useful. Specifically the answers about how they would use the proposed solution and the circumstances under which they thought it would be useful were used to develop the proposed framework. The responses about the safety incidents they witnessed in the past and near misses they prevented were used to develop the framework for emergency and critical conditions. The process of identifying themes from clusters of data had been recommended by Hycner R.H (1985, p. 290) in the process of analyzing interview data from a phenomenological standpoint. Bartlett D. (2004, p. 225) defines 'Code Density' as the percentage of times a particular code has appeared during qualitative data analysis. For the purpose of this research, code density is the percentage of interviewees that answered with a particular code. The following codes and the associated code densities from the interview data were used to develop the conceptual framework:

- It would be useful on large jobs (42%)
- It would be good to have an alarm system (26%)
- It is important to know where everyone is during an emergency situation (26%)
- It would be useful if crews are color coded (21%)
- It would be useful to track people by zones and off-limit areas (21%)

- Hazards on a construction site are constantly changing, so it is important to know where everyone is working (21%)
- It is difficult if not impossible to know where everyone is (21%)
- It would be useful during an emergency situation (16%)
- Location of people is important because congestion can lead to accidents (11%)

A conceptual framework to for combining RFID with BIM is presented in figure 2. In the first scenario, crews will be color-coded by their trade and their location will be tracked within the construction site. This method of tracking could be very useful in the construction of high-rise structures when several trades are working on different floors. In the second scenario, if an accident were to happen on a construction site, the superintendent starts the emergency action plan where all workers are required to come to a pre-decided muster point. This procedure also includes a head count to verify that all workers on site are accounted for. The head count process could be a tedious process when a few hundred workers are present on site. A third scenario in which workers can be tracked by color coded scheme, based on whether or not they are in the correct zone is being proposed. Instead of the superintendent looking at all the workers and identifying if they are in the correct place, this method would split the jobsite into various zones. Additionally all workers on site will be expected to be in certain areas, depending on what work is being done. If workers are not in the correct area, then those workers will be highlighted, thus suggesting to the superintendent that an action must be taken. In the last scenario, superintendents are often in meetings where they cannot oversee the work occurring on the construction site. This could also provide some measure of oversight for the superintendent that cannot go to all areas of the jobsite.

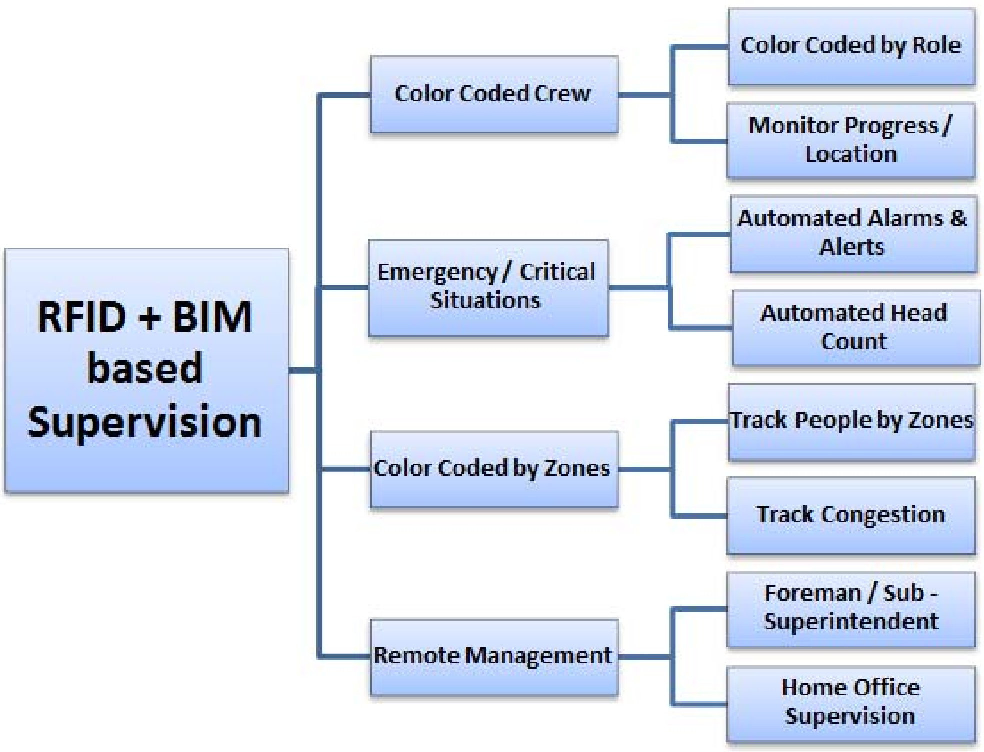

Figure 2. Conceptual Framework for RFID + BIM based Supervision.

5. CONCLUSIONS

The use of technology to assist in site safety monitoring is not new to the construction industry. Studies indicate that safety can be improved on a construction site using technological tools. The proposed research conceptual framework confirms that site superintendents are open to the use of technological tools to assist in site safety monitoring. Feedback from the superintendents was used to create a conceptual framework for combining RFID with BIM to formulate the suggested strategy of site safety monitoring. A survey has been created to validate the conceptual framework. The survey is currently being administered to industry professionals within construction. The survey results will be used to validate and create the final framework of site safety monitoring using RFID and BIM. A virtual prototype to combine RFID with BIM will be created and tested as part of this research.

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ESTIMATING THE COST OF NEW CONSTRUCTION PROJECTS USING AN INTEGRATED, COMPUTER-BASED APPROACH

Alfredo Serpell
Pontificia Universidad Católica de Chile, Santiago, Chile, aserpell@ing.puc.cl

José Manuel Rueda
Pontificia Universidad Católica de Chile, Santiago, Chile

Abstract

The availability of accurate conceptual cost estimates of construction projects is widely recognized as a key factor for project planning. However, estimating the cost of a project at this stage is a difficult problem because of the great uncertainty of forecasting the cost when the information, the scope definition of the project and the time available are very restricted. This paper addresses these limitations using an approach based on the application of case-based reasoning (CBR) and parametric estimating (PE) methodologies integrated in a computer system (CASEST). The CBR is applied for modeling the project scope of a new project and is based on the effective reuse of historical project scopes. The resulting project scope definition serves as the fundamental input for the conceptual cost estimate. The second method is applied to estimate the cost of the new project based on the resulting scope information and historical parametric estimating relationships that provide the quantities of work, and historical costs. For validation purposes, the system was tested in a construction company with actual data from 17 historic building projects. The system produced a suitably detailed and accurate cost estimate for each of the tested projects. Furthermore, the project scope defined by the system allowed the estimation of the cost of a new project to be performed more easily and provided a realistic work breakdown structure that can be used for different project planning purposes. The proposed approach would help construction estimators to generate more accurate cost estimates in a timely and more efficient way.

Keywords: case-based reasoning, cost estimating, parametric estimating, system, scope definition.

1. INTRODUCTION

At the conceptual stage, a cost estimate is one of the first cost planning outputs of a project and an important piece of information for decision making. As explained by Kim et al. (2012), the conceptual estimate of construction costs is an essential part of project planning. However, estimating the cost of a project at this stage is a difficult problem because of the great uncertainty of forecasting the cost of complex undertakings with information and definition of the project that are very restricted (Serpell, 1990). As stated by Staub-French et al. (2003), cost estimation is a typical example of a knowledge-intensive task.

Preliminary cost estimates are susceptible to inaccuracies (bias) because they are often prepared within a limited timeframe, and without a finalized project scope (Aibinu and Pasco, 2008). As explained by Caputo and Pelagagge (2007) in such cases, only incomplete or uncertain scope data is usually available, and proper cost calculation methods are required if future costs are to be predicted fairly accurately from such unreliable information.

An appropriate scope definition is an essential factor for the achievement of good conceptual cost estimates and for the success of projects in later stages (Serpell, 1990; CII, 1995; CII, 1997, Oberlender and Trost, 2003; Gibson and Pappas, 2003; Serpell, 2004). Without this element, it is difficult to know with an adequate accuracy, the approximate cost of all the components necessary to construct the project.

In order to contribute to the solution of these problems, a methodology for the definition of the scope and the estimation of a new project' cost is proposed. The methodology is built upon two methods already available: (1) the case-based reasoning (CBR) method, an artificial intelligence approach to problem solving based on the reusing of information which is applied in this case for scope definition, and (2) the parametric modeling method for cost estimation. The novelty of this methodology is explained by the well-grounded integration of the two methods (Rueda, 2006).

2. BACKGROUND

In the last decades, many different methods have been proposed for the estimation of the cost of construction projects at initial stages. Several methods based on statistics and on linear regression analysis have been reported in the literature mainly in the seventies and eighties and also later (Wilson, 1982; Bowen and Edwards, 1985; Meisl, 1988; NASA, 1983; Rödl et al., 1985; Wyskida, 1987; Kim et al., 2004). The development of new approaches based on artificial intelligence tools, mainly expert systems (Serpell, 1990; Allwood, 1989; Ashley et al., 1988, Rounds, 1986; Yau and Yang, 1998), neural methods (Caputo and Pelagagge, 2007; Kim et al., 2004) and case-based reasoning (Yau and Yang, 1998;; Kim et al., 2004; An et al., 2007; Dikmen et al., 2007, Koo et al., 2011, Jin et al., 2012), have been proposed later.

2.1 Case-based reasoning and scope definition

Usually, historical information of previous projects' scopes has been collected and used by estimators to establish a basis for a new project's scope. In this process, the most similar available historical project is normally selected for defining an initial scope for the new project. Following this procedure, the CBR method was found suitable for approaching the scope definition problem. As reported in the literature, the CBR method is effective for obtaining a solution for a new project by using specific knowledge and information gained from a previous project and it has been used in different construction areas and problems (Yau and Yang, 1998; An et al., 2007; Dikmen et al., 2007; Mubarak, 2004).

The CBR process is similar to the reasoning of experts who rely on their experiences to find similarities between old and new problems, to solve new problems (An et al, 2007). In CBR, experience is captured and organized as a set of historical cases stored in a database. Similar cases are recalled from the database to solve problems or provide suggestions (Yau and Yang, 1998). The recovery of cases is then a critical step in CBR systems. The objective of the recovery process is to find the historical experience that better resembles the new problem. Generally the resemblances among characteristic or attributes that describe the cases are evaluated and a measure of similarity is calculated and expressed in numeric terms.

A next step in the application of CBR is the adaptation of cases. This is achieved by means of processes of adaptation like the application of parametric adjustments, the substitution of elements or the use of models of adaptation, among many other techniques. Once the process of adaptation is concluded, the new case or solution surrendered by the system is ready to be applied to the new problem.

An important aspect of CBR is the representation of the cases. Figure 1 presents a building project example of the case representation approach proposed for the Project Scope Modeling Methodology used in the proposed system (Serpell, 2011). A scope modeling case contains a problem and a solution part. The problem part is represented as a "project description" or list of project parameters in the form of attribute-value pairs. The solution stores all the scope related information, which is represented as a tree or hierarchical structure similar to a Project Breakdown Structure.

SCOPE MODELING CASE

PROBLEM - Project Description

Attribute	Value
Basement area [m^2]	960
Building footprint [m^2]	1.930
Building area [m^2]	11.800
Building levels	6
Average level height [m]	2,7
	Reinforced

SOLUTION - Scope Definition

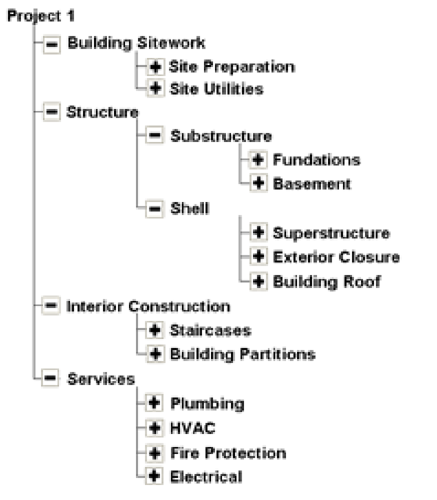

Figure 1 A case representation of a building project

In a CBR problem solving cycle, the case attributes along with its values allow to evaluate the similarity between cases in order to retrieve the appropriate information. The selection of the attributes for a case-based decision support system is a domain dependent activity. The example of the Figure 1 shows a set of attributes that may be useful for describing building projects. As explained by Watson (1997) attributes must be predictive in a useful manner, influencing the outcome of the process and describing the circumstances in which a case is expected to be retrieved in the future. The process of search, retrieval, use and storage of information can be very irregular when performed manually. Unfortunately the construction industry provides an overview of cost estimating practices characterized by very limited automation (Sawyer and Grogan, 2002; Phair 2003). Performing tasks manually for project scoping represents a high consumption of time and a considerable effort.

2.2 Parametric estimating methodology

The parametric cost model is an extremely useful tool for preparing early parametric estimates when there are little technical data or engineering deliverables to provide a basis for using more detailed estimating methods. Bajaj et al. (2002) also state that parametric estimating can be quite accurate if the historical data used in estimating preparation are properly captured from the source. If sufficient and reliable historical data is available and parameters have been well developed from this data using appropriate mathematical techniques, then the parametric estimating methodology might provide quite accurate cost estimates of new projects from limited information as long as historical data is available.

The parametric estimating method is based on Cost Estimating Relationships (CER's) that are derived from historical data through statistical analysis. These relationships are used to compute new estimates once the scope of a new project is preliminary defined. For example, the most basic relationship is the one that relates the gross square meters of a building and its cost. Knowing the gross square meters of a new building it is possible to use the relationships derived from a number of historical projects, to calculate the cost of the new one. As explained by Jrade and Alkass (2007), the data models used in the preparation of a parametric estimate are essential to the process.

3. CASEST - AN INTEGRATED COMPUTER-BASED ESTIMATION SYSTEM

CASEST (Computer Assisted Estimating System) is a prototypical system constructed to prove the proposed estimating approach. It automatically generates construction cost estimates using the scopes obtained with the Project Scope Modeling Methodology. Figure 2 depicts the system architecture. CASEST is formed by three basic types of components: the user interface, the system program modules, and the system databases. This prototype was developed using the following tools: MS Excel, MS Access, and SQL (Rueda, 2006).

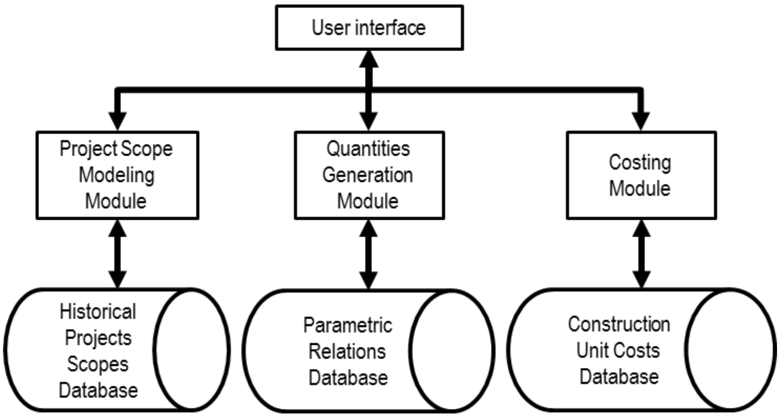

Figure 2 Structure of CASEST

In CASEST, a program module for Project Scope Modeling executes all the support tasks to assist the preparation of a new project scope definition.

3.1 How CASEST works – a brief description

The proposed scope modeling methodology allows configuring the scope of a new project by reusing the most relevant historical information (scopes of historical projects). The relevance of the information can be measured in numeric terms based on an objective evaluation of the similarity between the new project and historical projects (cases). The problem part in this case is represented by a project's attributes and their values, reflecting in this way the needs that the solution (or historical scope definition) should adequately satisfy. In one case, if a complete historical scope is available in the database, this can be applied to the new project, and the implicit knowledge stored in a similar previous solution used to solve the current problem as shown in Figure 3. However, if an important quantity of descriptive information and a work breakdown structure of a new case are available, scope composition schemes can be applied. The methodology proposes a three step modeling process to prepare a new scope definition: 1) to describe the new project; 2) to evaluate similarity and retrieve an initial solution; and 3) to adjust the initially selected scope.

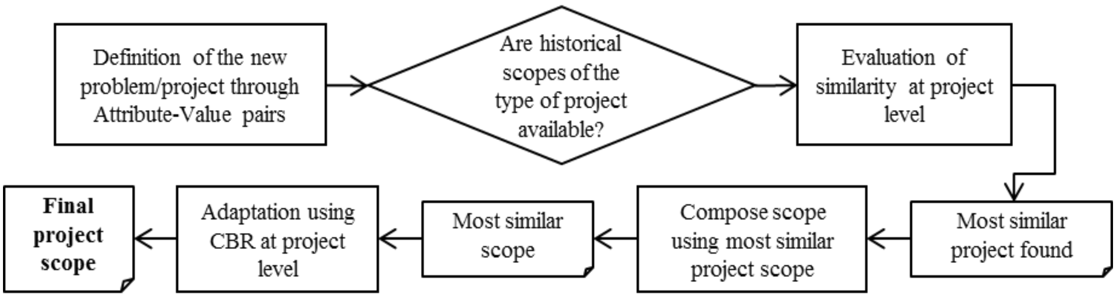

Figure 3 Definition of a new scope based on historical projects' scopes

In the first step, the modeling system presents the user a set of attributes (previously selected according to the type of project). The user then enters a value for each attribute. The list of attribute-value pairs makes it possible to start the evaluation of the similarity between the new project and the stored cases. The objective of these comparisons is to determine which historical case is the most similar to the new problem and then to retrieve it from the base of cases. Similarity between the two cases is measured using the Nearest Neighbor algorithm by comparing what is the degree of similarity of the values defined for each of the projects' attributes (Serpell, 2011). The similarity between two cases is evaluated as the weighted sum of attributes' similarity, and the greatest challenge in this case is the determination of the weights that will be used for each attribute.

3.2 Determination of quantities of work and costs

Once a new breakdown structure have been prepared, CASEST generates project quantities which are the input information for obtaining construction costs. The approach used by CASEST takes the information input of the attribute/value pairs of the new project and uses them to determine the quantities. To achieve this goal, numerous parametric relationships developed from historical cases are utilized. Following this approach, the approximate quantities of work can be determined at different abstraction levels, depending on the existing relationships. Afterwards, the costing program module multiplies all project quantities by their corresponding construction unit costs using data from a cost database. Estimating reports are then generated and presented to the user.

3.3 System Validation

Data from 17 building projects constructed in the city of Santiago, Chile were used for validation purposes. The data was contributed by an important construction company specialized in building construction (Rueda, 2006; Serpell, 2011). All buildings were designed in reinforced concrete and the real final cost of each one was known. The validation process consisted in estimating construction project costs of the described projects, using the CASEST prototype. The proposed automated scheme allowed carrying out the conceptual estimating processes with a low effort and time. Estimated costs were compared later with real construction costs to obtain accuracy results. The estimates so obtained had an accuracy that varied between -23.8% and +17.4% with an average deviation equal to 9.8% (Serpell, 2011).

4. THE CASEST PROTOTYPE

4.1 Main characteristics

For the development of the prototype, it was decided to utilize development tools that are extensively used in cost estimating. The tools employed in the system are shown in Figure 4. The database of cases was built with the collaboration of construction professionals that provided useful information from real construction projects. Information was gathered about the historical scoped of building projects, descriptive attributes at conceptual level, construction dates, work quantities, and construction unit costs.

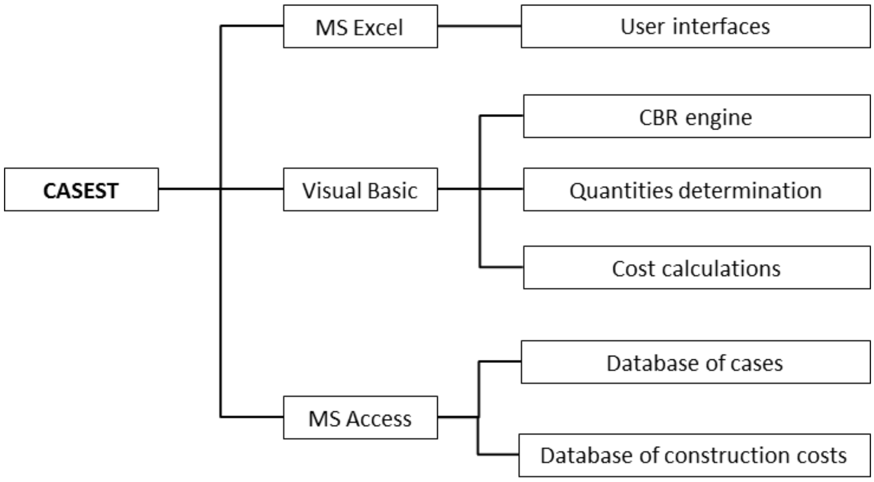

Figure 4 Tools used by CASEST

4.2 Example of conceptual estimation in CASEST

The CASEST estimation process starts with the definition of the characteristics that describe the new project at the conceptual level. The estimator provides a description of the new project by attribute-value pairs using a definition interface problems. In each step, the user has to input the value of a specific descriptive attribute. For this example, the following values were input into CASEST:

Total building area above basement: 15,600 m2

Number of floors above basement: 18

Total area of basement levels: 4,600 m2

Number of basement levels: 3

Total area of the building footprint: 870 m2

Structure of the building: Reinforced concrete

If necessary the user can now edit the weights for each attribute using the interface, as shown in Figure 5. The sum of all the weights always adds to 100%. After the adjustment of weights, the system evaluates the similarity and informs the user if a scope definition appropriate for the new project has been found. Then the system shows the selected scope and the user can start adapting the scope by modifying it to achieve the best scope definition for the new project. The user or estimator reviews the work breakdown structure (WBS) looking for important elements that are missing and need to be added and elements not needed that should be eliminated.

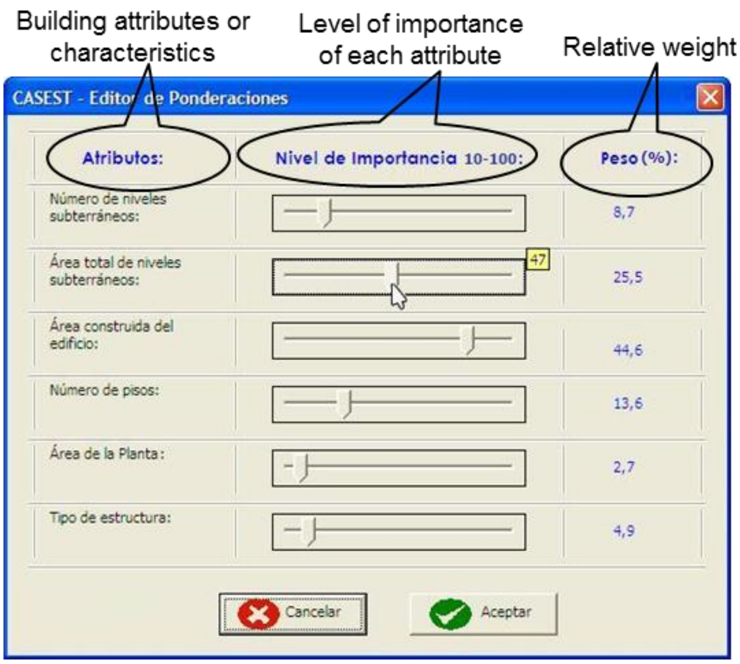

Figure 5 Edition of relative weights of characteristics in CASEST

This can be done at each level of the WBS. As shown in Figure 6a, using information from the three projects most similar to the new one, the estimator can add the complete configuration of one element or only add each component individually. For this, the system presents the elements available for modifications. Figure 6b shows the WBS with the addition of a Meeting Room.

When the adaptation process has finished, the estimator can push the button ***Reporte*** (Report) in the interface. At this moment, the prototype CASEST continues with the application of the parametric model and computes the quantities of work of the project. In addition and using the unit costs database, the system computes the cost of each work package. This report is shown in Figure 7. As it is shown, the estimating outcomes are presented as detailed items allowing knowing: 1) the estimated total cost of the Project, 2) the estimated cost of any component of interest, and 3) the estimated cost of an element within a component.

During the adjustment process, it is also possible to get information about the outcomes of the similarity evaluation as shown in Figure 8. In this case the attributes of the most similar project is compared to the attributes input by the user for the new project.

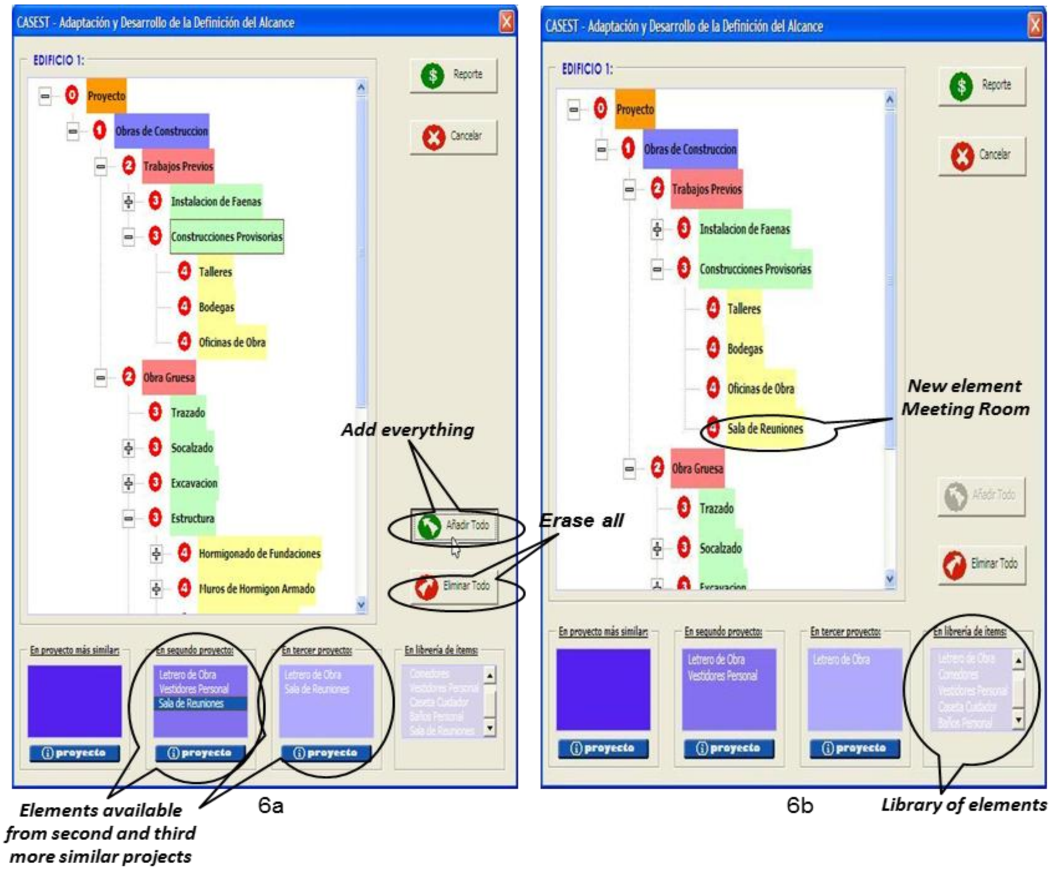

Figure 6 Adición de elementos en la interfaz de adaptación del alcance

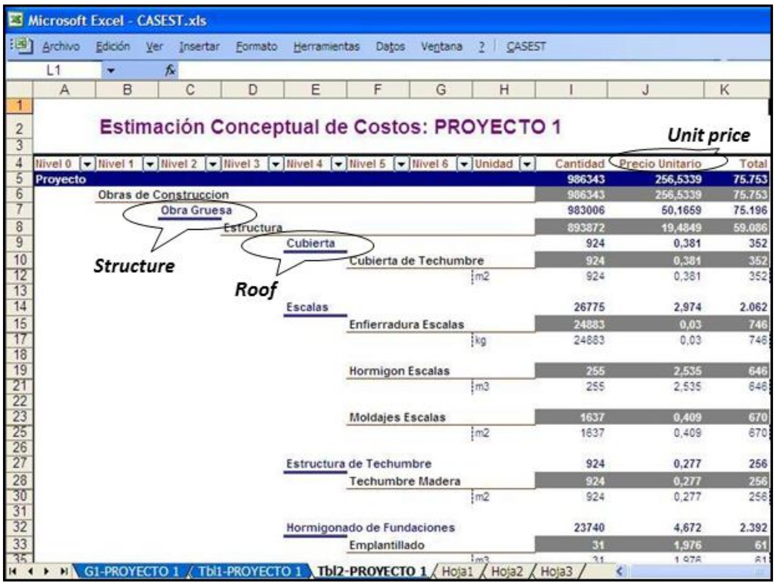

Figure 7 Estimation report generated by CASEST

5. CONCLUSIONS

Case based reasoning decision support has been proposed for project scope modeling and a prototypical system for scope modeling and conceptual cost estimating was described. The automation and support of CBR problem solving seems to make possible to carry out the scope definition process of a project in a short time and without too much effort. Each stage of the process can be assisted without the participation of manual information handling. Large amounts of scope related information from numerous historical projects can be quickly evaluated for similarity, retrieved, and combined to create a scope for a new project.

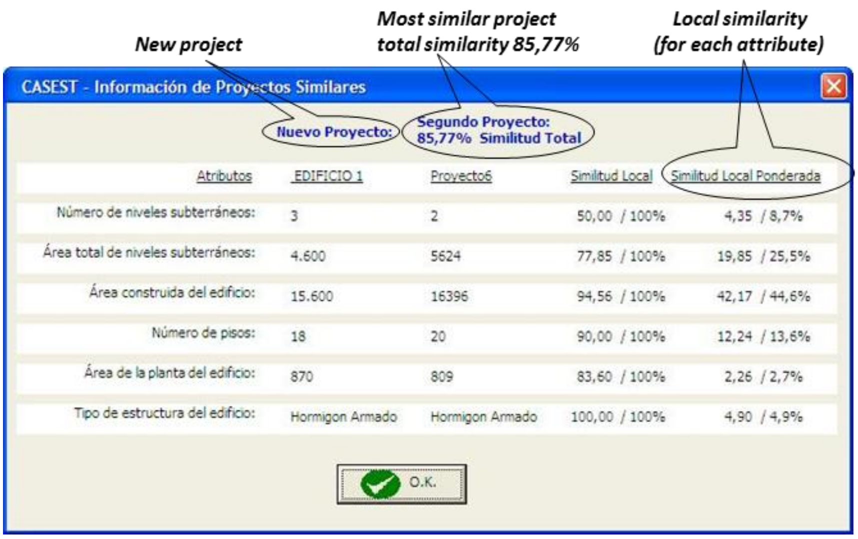

Figure 8 Report of similarity between projects

The breakdown structures obtained through the application of the methodology can be used in a computer environment as input information for planning purposes. With the application of the scope modeling methodology it is possible to obtain detailed cost estimations that allow knowing the total cost of the project and also the detailed costs of the main components and elements, improving in this way the monitoring and control processes later.

Historical information is the most critical element for the CBR and also for the conceptual estimation of costs. It turns out to be indispensable to have good and reliable historical information to apply the scope modeling and the estimating methodologies.

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REUSE OF CONSTRUCTION WASTES AS AGGREGATES IN CONCRETE.
(A case study of Allama Iqbal Open University-Pakistan)

Attaullah Shah
Allama Iqbal Open University Islamabad Pakistan (pdaiou@yahoo.com)

Ehsan. U. Qazi
National Institute of Science and Technical Education Pakistan (Engr59@gmail.com)

S. M. Ahmed
Construction Management department East Carolina University USA (smahmed05@gmail.com)

Abstract

The fast urbanization and rapid construction in the developing countries are producing a huge burden on the natural resources. At the same time old buildings and infrastructure are also enhanced, upgraded and modernized to accommodate the new technological demands of growing populations. This has led to generation of substantial volume of construction wastes in the developing countries of Asia. The transportation and disposal of construction wastes require additional resources, which severely affect other projects of the municipal authorities. One of the options to reduce the burden of such construction wastes is to utilize such wastes as construction ingredients such as aggregates and sands for concrete. The reuse of such aggregates in the concrete would reduce the disposal costs of construction wastes at one hand and burden on natural resources in terms of resource harvesting on the other hand.

In this research work the construction solid wastes collected from the demolished old buildings of Allama Iqbal Open University Pakistan have been segregated, graded and utilized as aggregates in cement concrete. Various mix design of concrete have been prepared and tested in the laboratory to check it compressive strength and suitability for the construction purposes. The concrete cylinders and cubes cast from the recycled aggregates were tested in the lab and failure patterns of these samples were observed closely. The results have shown that there are ample opportunities of re-using the solid wastes as aggregates and sands in the concrete and new constructions in developing countries.

Keywords: urbanization, reuse, solid wastes, construction wastes.

INTRODUCTION

The infrastructure development is pre-requisite for economic development across the world. In the post globalization era, the ease of transfer of financial and physical resources and specialization of human resources has given impetus to the construction industry both in developing and developed countries. The construction industry is expected to boost once again in the current decade. According to latest report, the construction industry is expected to grow by 67% up to 2020 from its present level of $7.2 trillion to $12 trillion per annum. While growth has definitely been constrained in North America and Europe, the emerging economies of Asia and Latin America are expected to lead the recovery in the construction sector [Global Construction 2020].

Apart from construction of new infrastructure, a large number of buildings are reconstructed and upgraded in developing countries. Construction and Demolition Wastes (CDW) constitute about 40% of the total waste generated in the world. According to definition of US EPA (1998) “Construction and Demolition Wastes (CDW) are waste material produced in the process of construction, renovation and demolition of structures”. The structures include residential, non residential buildings, roads & bridges of all types. The typical components of C&D wastes are concrete, bricks, asphalt, gypsum wall boards, metal and woods. The CDW are increasing in all parts of the world due to enhanced construction activities on one hand and renovations, refurbishments of the existing physical infrastructure on the other hand.

The Gulf Cooperation Countries (GCC) produces 120 million tons of solid waste every year in which about 15% is construction wastes (Gulf Today,2010). Kartam *et al.* (2004), AlNaser Flanagan(2007) and Kayali *et al* (2008) discussed the current status of construction and demolition waste disposal systems, alternative solutions to manage and control this waste in an economical, efficient and safe way and the available industrial waste products that can be used in making sustainable concrete and their relevance to the Middle East and other parts of the world. Galbraith (2008) outlined the role of structural design in sustainable buildings and its implication within the Gulf region. Gilpin *et al* (2004) explored the opportunities for reusing the recycled aggregates from asphalt concrete and cement concrete in the new concrete construction.

The annual volume of CDW in Hong Kong has crossed 14 million tons. The Govt. of Hong Kong has formulated two sets of specification for use of recycled aggregates in construction activities (WBHK,2002). Similarly about 200 million tons of rubble from the construction industry and building demolition is produced annually in the European Union (EU). Fonteboa *et al* (2005) checked the different rheological properties of concrete incorporating various mix proportioning of the recycled aggregates. They observed that recycled concrete aggregates in Spain are favorably comparable with the natural aggregates in terms of their physical properties and strength parameters. Jimeniz *et al* (2011) worked on use of CDW as granular material in sub base construction of unbound roads for various traffic loads. They used various forms of recycled material such as mixed debris, recycled concrete aggregates etc. They reported that if good level of quality control is exercised, recycled concrete aggregates can give better results for unbound roads. Akash *et al* (2007) studied the effects of recycled aggregates on the properties of fresh and hardened concrete and recommended to create awareness, governmental support and development of specifications/codes for reusing these aggregates in the developing countries.

The use of recycled aggregates from CDW is becoming a popular option in many developing countries of Asia, mainly due to the initiatives of the respective Governments. In Kuwait, Al-Mutairi and Haque (2003) used old demolished concrete to replace 50 and 100% of the coarse aggregate and seawater to replace 25, 50 and 100% of the tap water in a standard concrete mix having moderate target strength. The recycled concrete was cured in seawater for a period of 28 days. The results indicated that even with 100% usage of recycled concrete aggregate, design strength of 35 MPa was attainable. Highest concrete strength was obtained when the mixing water consisted of a blend of 25% seawater and 75% tap water. Al-Harthy *et al*. (2007) conducted laboratory tests to examine the strength and durability of recycled aggregate concrete. The results showed that concrete strength is enhanced with the replacement of normal aggregates by recycled aggregate content of up to 30%, thereafter the strength decreases with further increase in recycled aggregate.

Fong *et al* (2004) showed that under normal water temperature, steam curing has increased the early strengths but reduced the long-term strengths for all normal and recycled aggregate concretes. Chen *et al* (2003) used the construction rubbles including bricks and tiles as replacement to aggregates in various proportions. Poon *et al* (2004) used the recycled aggregates in the construction of concrete blocks and bricks. Michael H *et al* (2011) studied the effects of low grade recycled concrete with mineral ad-mixtures on the mechanical and environmental performance of concrete.

American Concrete Institute (ACI) has focused on reuse of hardened concrete. The Recycled Concrete Aggregates (RCA) contain crushed sound and clean concrete by 95% of the total weight of concrete and contamination of 1% or less. The brick contents in RCA have to be limited to 0.5% of the total weight of concrete. The use of RCA has been mainly recommended for footpaths, kerbs, sideways, gutter etc.

The mix proportioning of recycled aggregates require detailed analysis of the aggregates and its physical and chemical properties. Bairagi *el al* (1993) studied the behavior of fresh and hardened concrete for various mix proportions of recycled concrete and recommended empirical relations for moduli of elasticity and rapture of concrete.

Environmental sustainability requires resource conservation in the design, construction and maintenance stages of physical development. The three major resources normally used in the built environment include material, water and energy. The conservation of all these sources demand to apply the principles of 3R (Reduce, Reuse and Recycle) in the construction industry as well. The reuse of recycled concrete is thus becoming an economically and environmentally viable option for resource conservation in the construction industry. The economic gains in short term may not be very promising as the transportation, handling, segregation and crushing as well as gradation of the recycled aggregates involve additional costs, but its environmental gains in the form low carbon emission, conservation of natural resources, reuse of waste material and low global warming impact of construction activities may be high significance in times to come. That is why the Life Cycle Assessment (LCA) is becoming more powerful tool for the design and construction & manufacturing of new infrastructure.

RE-USE OF RECYCLED CONSTRUCTION AND DEMOLITION WASTE IN CONCRETE

There has been extensive research on exploring the uses of CDW for re-use and recycling in concrete. The typical application of such material includes its use as recycled aggregates in concrete. Recycled aggregates are obtained from processing of concrete previously used. Some of the commonly used recycled aggregates include the following types:

– Recycled Concrete Aggregate (RCA)
– Recycled Concrete and Masonry (RCM)
– Reclaimed Aggregate (RA)
– Reclaimed Asphalt Pavement (RAP)
– Reclaimed Asphalt Aggregate (RAA)
– Glass Cullet
– Scrap Tires
– Used Foundry Sand

American Concrete Institute (ACI) has focused on reuse of hardened concrete. The Recycled Concrete Aggregates (RCA) contain crushed sound and clean concrete by 95% of the total weight of concrete and contamination of 1% or less. The brick contents in RCA have to be limited to 0.5% of the total weight of concrete. The use of RCA has been mainly recommended for footpaths, kerbs, sideways, gutter etc. To limited extent RCA are used for structural members but here the RCA must be impervious and sound. RCA are commercially available in many developed countries. The Recycled Concrete and Masonry aggregates (RCM) must have not more than 30% of the crushed bricks. RCM are used in road sub bases and base courses. In some parts of the world RCM are commercially available. The Reclaimed Aggregates (RA) are separated from cement slurry of the refused concrete from batching plants etc and can be used effectively for developing the structural and non structural concrete provided that the aggregates are separated carefully. Reclaimed Asphalt Pavements (RAP) are obtained from old pavements and are widely used in the new asphalt concrete pavements. Sometimes RCA and PAP are blended to make aggregates for flexible pavements.

The use of recycled aggregates from CDW is becoming a popular option in many developing countries of Asia, mainly due to the initiatives of the respective Governments. Rafi *et al* (2011) used the recycled aggregates (RA) from construction and demolition wastes in the hot mixed asphalt (HMA) mixture. They used 50% recycled aggregates with the natural aggregates in the asphalt mix prepared in accordance to the requirements for wearing course as per National Highway Authority Pakistan specification. They and conducted various tests and reported good performance of the HMA.

In Kuwait, Al-Mutairi and Haque (2010) used old demolished concrete to replace 50 and 100% of the coarse aggregate and seawater to replace 25, 50 and 100% of the tap water in a standard concrete mix having moderate target strength. The recycled concrete was cured in seawater for a period of 28 days. The results indicated that even with 100% usage of recycled concrete aggregate, design strength of 35 MPa was attainable. Highest concrete strength was obtained when the mixing water consisted of a blend of 25% seawater and 75% tap water. Al-Harthy *et al* (2007) conducted laboratory tests to examine the strength and durability of recycled aggregate concrete. The results showed that concrete strength is enhanced with the replacement of normal aggregates by recycled aggregate content of up to 30%, thereafter the strength decreases with further increase in recycled aggregate. Fong *et al* (2010) applied steam curing techniques to concrete made with recycled aggregates and preliminary results indicated that compared with concretes cured under normal water temperature, steam curing increased the early strengths but reduced the long-term strengths for all normal and recycled aggregate concretes. Chen *et al* (2003) used the construction rubbles including bricks and tiles as replacement to aggregates in various proportions from 0% to 67%. They also proposed a flowchart for the preparation and processing of recycled aggregates. Rakshvir *et al* (2006), used various proportions of recycled aggregates and studied different mechanical and rheological properties of concrete. They showed that the water requirements have been increased with the use of recycled aggregates.

CONSTRUCTION AND DEMOLITION WASTE IN PAKISTAN

The construction industry of Pakistan is, unfortunately, traditional and static in nature. The low productivity of the inputs particularly human resource, the lack of support from the Government & financial institutions and poor project management practices has led to an insignificant role of the construction industry towards economic development of the country. The contribution of construction industry towards the GDP of Pakistan is merely 2.3 % against the global standards of around 6-9% and provides employment to about 6% of the total employed human resource [Raza.A.Khan,2008]. There is however a sharp increase in the construction activities and the real estate market has started performing well in the last few years. This is mainly due to poor performance of manufacturing and financial sectors at one hand and growing depreciation of the national currency against dollar on the other hand. The investors are diverting huge resources to construction industry of Pakistan. A large number of old buildings are upgrade and renovated for making it fit to modern technological and functional uses.

SOLID WASTE MANAGEMENT IN ISLAMABAD PAKISTAN

Islamabad the Capital of Pakistan is administratively controlled by Capital Development Authority (CDA). The collection and disposal of Municipal Solid Waste (MSW) is administered by CDA. Previously the MSW was collected and disposed off in Sector H-11 in open dumping and sometimes burning was also exercised. On account of habitation in the vicinity and objections of environmentalists, the site was closed and shifted to I-14 sector. The area earmarked for the purpose is about 500,000 square feet. Since Year-2003, the MSW were being dumped in the location, the average depth being about 15 feet. Up till now as reported by CDA, about 1.4 million tons of MSW have been disposed off in the location. The MSW collected from the city is transported to green belt of Sector-I-14; previously was dumped in an unsanitary way, but presently, a sort of sanitary land fill is practiced. Recently, under an arrangement, local cement factory (Fauji Foundation) after screening is lifting MSW for use as fuel in its cement plant (2005). The CDA on the basis of daily collection and transportation to the site of dumping has assessed quantity of MSW as 550-600 tons per day, out of this generated MSW, about 500 tons are collected and disposed off. The collection efficiency as such is about 83%. The sector-wise generation of MSW is given in Table 1

Table1 Sector-wise MSW generation of Islamabad Pakistan.

Nr.	Sector	Amount of Waste, tons/day	Nr.	Sector	Amount of Waste, tons/day
1	E-8	1.2	11	G-7	20.7
2	E-9	2.7	12	G-8	12.2
3	F-5	14.2	13	G-9	22
4	F-6	11.2	14	G-10	12.5
5	F-7 & E-7	19.3	15	G-11	5.7
6	F-8	23.6	16	I-8 / H-8	46.3
7	F-10	10.6	17	I-9 / H-9	7.2
8	F-11	6.1	18	I-10	37.1
9	G-5	1.3	19	I-11	85.8
10	G-6	82.8		Total	422.5

Source: *Waste Amount Survey in Islamabad, JICA/EPA*

The survey of MSW generation was carried out to assess the daily per capita generation of MSW. The results of various studies are given in Table 2

Table 2 Details of MSW generation on the basis of various studies

No.	Description	Year	Daily Generation tons	Year	Daily Generation tons
1	JICA	2004	422.5	2011	636
2	CAGP	2006	425.751	2011	571
3	Present Study	2011		2011	866
4	CDA Assessment	2011		2011	600
	Average				668.25

Source: Waste Amount Survey in Islamabad, JICA/EPA

On the basis of assessed growth rate, the projected MSW is given in Fig.1. It is estimated that the SWM generation of Islamabad will increase to 2689 tons per day by year 2040.

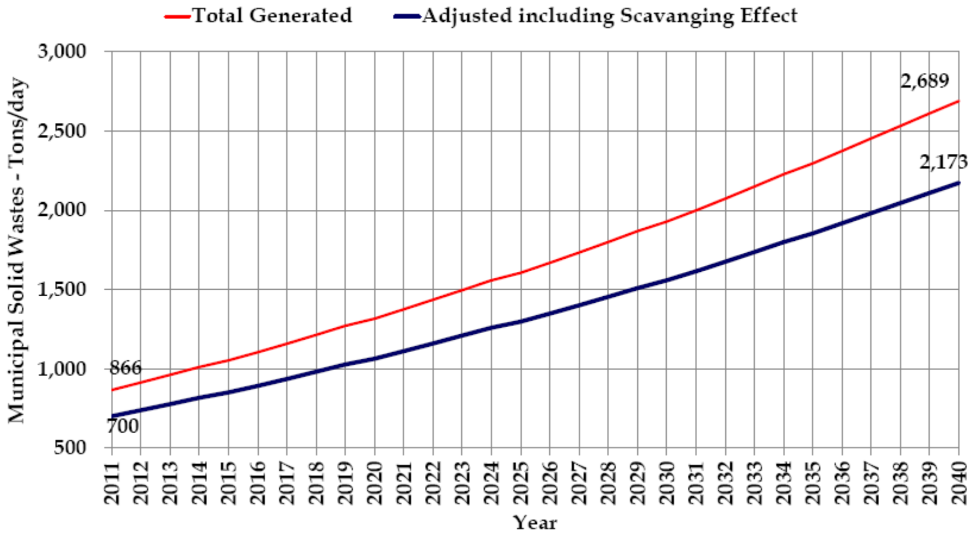
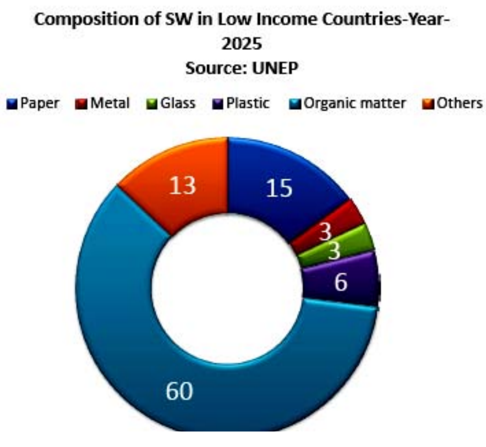


Fig 1 Projected MSW generation from Islamabad by 2040

The composition of MSW changes from area to area of the city depending on the social and economical status of the community in the particular sector. According to UNEP, the composition of MSW in the low income countries is given in Fig 2.



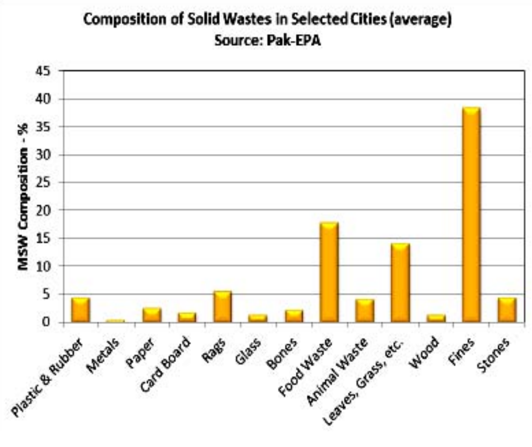


Fig 2 Composition of MSW in Low income countries and Pakistan [UNEP/Pak EPA].

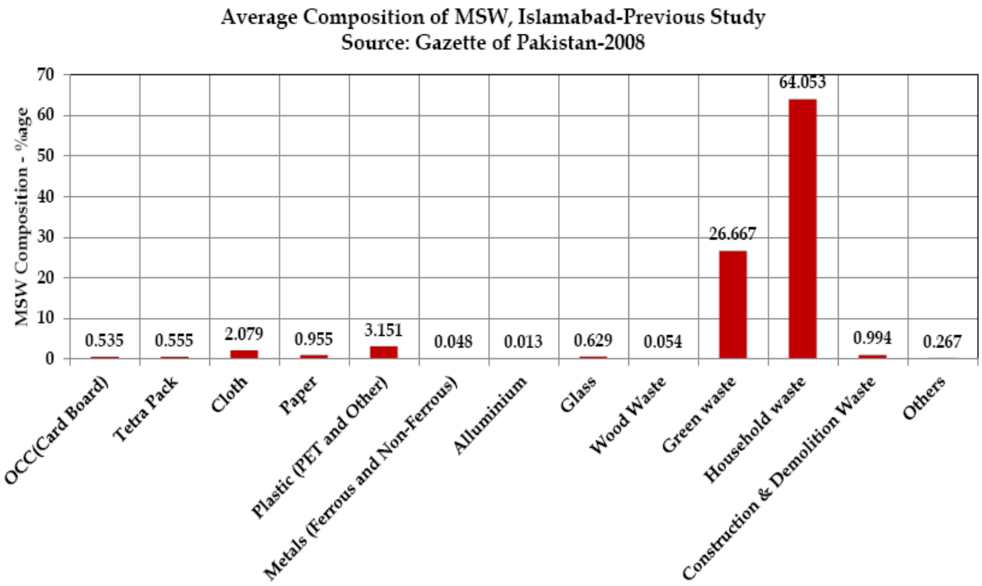


Fig 3 Composition of MSW in Islamabad Pakistan (Gazette of Pakistan, 2008).

The composition of MSW in Islamabad as per Gazette of Pakistan (2008) is given in Fig 3. About 91 % of total waste in Islamabad is comprised of green and household waste, which gives a viability of compost plant. Whereas, the remaining waste of 9% comprised of plastic 3%, Cloth 2% and paper, glass and construction material at 1 % each. The cloth is not picked up by the scavengers. The Waste Characterization Study (WCS) of various sectors has shown that the Construction and Demolition Waste (CDW) is presently about 1% of the total MSW of Islamabad which is very small as compared with the rest of the country. The main reason is the stringent monitoring and controlling mechanism adopted by the CDA authorities. However this can increase further as the available stock of the buildings of the capital has to be either demolished or refurbished and upgraded to account for the growing functional and technological needs of the city (2004). The CDW is presently mainly used for dumping in the low lying areas with no re-use and recycling efforts in Pakistan. Very local research has been conducted on the reuse and recycling of the construction waste. This research work involves re-using of the CDW in concrete aggregates. The MSW collected from the Allama Iqbal Open University has been used for the purpose.

In this research work, the construction and demolition waste in Allama Iqbal Open University has been used for producing concrete.

MATERIALS AND METHODS

Material

The MSW collected from the Allama Iqbal Open University (AIOU) was used for the research work. The demolished material collected from the construction site was crushed with the help of jaw crusher to the desired sizes. The gradation of the done as per ASTM methods and the results of the sieve analysis is given in Table 3.

Table 3 Gradation and sieve analysis of crushed reused coarse aggregates used

Sieve size/#	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
1in	78	0.78	99.22	**0.78**
¾in	1136	11.36	87.86	**12.14**
½in	6436	64.36	23.5	**76.5**
3/8in	1281	12.81	10.69	**89.31**
#4	9860	9.86	0.83	**99.17**
Pan	83	0.83	0	**-**

For fine aggregates, sand collected from local source of Lawrencepur River was used. The sieve analysis of the fine aggregates is shown in Table 4.

Fineness modulus $= \dfrac{\sum \text{Cumulative \% retained}}{100}$

Fineness modulus = 2.22

To check the resistance to degradation, Los Angeles abrasion test for the coarse aggregates, was carried out as per ASTM C535 – 09 methods. The data of test results is given in Table 5.

Table 4 Gradation and sieve analysis of crushed reused coarse aggregates used

Sieve size/#	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
# 4	0	0	100	**0**
#8	0	0	100	**0**
#16	11	0.40	99.60	**0.40**
#30	1243	49.83	49.76	**50.24**
#50	663	26.58	23.17	**76.82**
#100	462	18.52	4.64	**95.35**
#200	97	3.88	1.05	98.94
Pan	18	0.72	0.32	99

Sample taken = 1000 gm (10kg)

Weight of sample taken = w_1 = 10kg

Weight of aggregates greater than #10 sieve = w_2 =7.442kg

Loss = w_1-w_2 =10 – 7.442 = 2.528

Abrasion loss % = (2.528/10)x100 = 25.28%. The value is reasonable for the use in concrete.

Ordinary Portland Cement (OPC) type-1 was used conforming to ASTM C150-97.

Table 5: The sieve analysis of the coarse aggregates after abrasion test.

Sieve #	Mass retained (gm)	Retained %	Cumulative % passing	Cumulative % retained
1in	0	0	100	**0**
¾in	378	3.86	96.14	**3.86**
½in	5013	51.23	44.91	**55.09**
3/8in	440	4.49	40.42	**59.58**
#4	978	9.99	30.43	**69.57**
Pan	2976	30.43	-	

Mix Design of Concrete

For concrete mix design, the nominal ratio of 1:1.8:3.6 was used by weight. In controlled mix, natural aggregates were used. The proportion of the ingredients was kept the same for both the Natural Aggregates Concrete (NAC) and Recycled Aggregates Concrete (RCA). The standard cylinder of 150mm diameter and 300mm depth was used as per ACI-318 standards. The slump of concrete was fixed at 50mm and clean potable water was used. The water cement ratio was adjusted to achieve the desired concrete slump. The substitution of natural aggregates was done with recycled aggregates in 25%,50%,75% and 100%. These concretes have been labeled as RAC-25, RAC-50, RAC-75 and RAC-100. The concrete with natural aggregate was labeled as NCA. Three concrete cylinders were cast from each types of concrete i.e. NAC, RAC-25, RAC--50; RAC-75 and RAC-100 and a total of 15 cylinders were cast at the specified max design as already explained. The slump of the concrete was measured with Slump Cone.

Testing of Concrete cylinders

To check the compressive strength of the cylinders, concrete crushing machine was used as shown in Fig.4.

Fig.4 Concrete compressive crushing strength machine.

The cylinders were tested under compression testing machine and the loads were gradually applied with the hydraulic load system. The cracking pattern of the cylinders and crushing strength was noted for each sample.

RESULTS AND DISCUSSIONS

The results of the compressive strength of RCA based concrete and other properties are given in Table 6.

Table 6. The compressive strength, water cement ratio, slump and other details of the natural and recycled aggregates concrete.

Concrete Type	Sample No.	Aggregates mix (%)		Nominal Mix Ratio (Cement:Sand:Agg)	w/c ratio	Slump (mm)	28 days Cylinder strength (MPa)
		Natural	Recycled				
NAC	NAC-01	100	0	1:2.8:3.6	55%	52	35.86
	NAC-02	100	0	1:2.8:3.6	57%	54	34.52
	NAC-02	100	0	1:2.8:3.6	60%	55	34.14
RAC-25	RAC-25-01	75	25	1:2.8:3.6	62%	48	32.42
	RAC-25-02	75	25	1:2.8:3.6	63%	50	31.17
	RAC-25-03	75	25	1:2.8:3.6	61%	51	31.01
RAC-50	RAC-50-01	50	50	1:2.8:3.6	65%	54	29.65
	RAC-50-02	50	50	1:2.8:3.6	64%	53	29.12
	RAC-50-03	50	50	1:2.8:3.6	62%	56	29.01
RAC-75	RAC-75-01	25	75	1:2.8:3.6	66%	59	26.89
	RAC-75-02	25	75	1:2.8:3.6	68%	53	27.14
	RAC-75-03	25	75	1:2.8:3.6	69%	54	26.32
RAC-100	RAC-100-01	0	100	1:2.8:3.6	70%	51	22.06
	RAC-100-02	0	100	1:2.8:3.6	74%	54	21.98
	RAC-100-03	0	100	1:2.8:3.6	72%	56	21.32

Water content of the Recycled Aggregates Concrete:

The water requirement of the RAC has been increased with the increase in the proportion of recycled aggregates in the concrete. This is mainly due to the fact the recycled aggregates contain a large part of the mortar sticking with the aggregates and cannot be removed even with crushing of the used concrete blocks. The mortar is relatively porous as compared to natural aggregates. This increase in water requirements has also contributed to the partly decrease of compressive strength of RAC. In cases where RAC is used on large scale, it is advisable to moist the aggregates to reduce the water requirements.

Compressive Strength of Concrete

Compressive strength of RAC decreased with the increase of the proportion of the recycled aggregates as compared to the controlled concrete of NAC. However with 100% replacement of natural aggregates with the recycled aggregates, the strength of concrete observed is reasonably good for its use as ordinary plain concrete. The use of RAC for structural components needs to be explored further.

Failure mechanism of Recycled Aggregates Concrete (RAC).

There a marked difference in the failure mechanism of NAC and RAC. In NAC, the failure normally occurs at the boundary of aggregates and the micro cracks passes through the cement mortar at the periphery of natural aggregates. The irregular shape of aggregates provides an interlocking property for concrete, which contributes to the increase in crushing strength in general and shear strength of concrete in particular. For high strength concrete, this aggregates interlocking is however reduced as due to high strength of the concrete mix, the aggregates are broken instead, before reaching at the level of aggregates interlocking. This is one of the major causes for the reduction of shear strength of high strength concrete. In RAC, the weak part of the concrete is the old mortar, as the strength of the previous mortar cannot be ascertained for new concrete. The cracks normally develop in the old concrete mortar as shown in Fig 5.

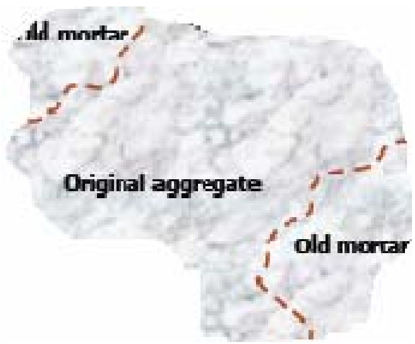


Fig. 5 Failure plains of old mortars in RAC.

CONCLUSIONS AND RECOMMENDATIONS

The aggregates form CDW can be used for the mass concrete, pavements and walkways on the basis of the strength of concrete achieved. The existing batching plants in the region needs separate facilities to crush, sort and grade the used aggregates for its potential use in the concrete. The mechanical properties of RAC for its use in structural concrete require extensive research in the region. There is a need to develop specification and testing procedure for recycled aggregates in the region. It is recommended that the countries of South East and South Asia may work collaboratively to explore opportunities for reusing and recycling of old concrete for aggregates.

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ENTERPRISE RESOURCE PLANNING SYSTEM FOR PERFORMANCE-BASED-MAINTENANCE OF CLINICS FACILITIES

Igal M. Shohet
Department of Structural Engineering, Ben-Gurion University of the Negev P.O.B. 653 Beer-Sheva 84105, Israel, e-mail: igals@bgu.ac.il

Abstract

Higher life expectancy as well as an increase in the number of both in- and out-patient admissions in acute care hospitals drove healthcare institutions in developed countries including Israel to shorten the duration of medical services provided by such acute care facilities. These services are replaced by community healthcare services that are provided under intensive service conditions, increasing the importance and significance of community clinics in the healthcare delivery system. The research hypotheses were defined as follows: (a) Using Key Performance Indicators (KPIs) based on performance and on Life Cycle Costs (LCC) principles, the maintenance and performance of clinics can be systematically monitored with a high degree of accuracy and reliability; (b) Implementation by clinics of the above-mentioned principles can contribute both to savings in their maintenance expenditure and to improved performance. A performance-based model was developed for clinic facilities. The model comprises eight Key Performance Indicators that refer to four core domains of healthcare facilities management: Asset Development, Maintenance Management, Performance Management, and Supply Chain Management. The eight Key Performance Indicators were integrated into an Enterprise Resource Planning (ERP) System for public clinic facilities maintenance using an *input interface*, an *inference engine* and an *output interface*. The inference engine is based on *deductive* inference of the clinic's profile and on *inductive* reasoning of the KPIs, to obtain the most effective maintenance and performance policy. Implementation of the model in 89 clinics resulted in increased efficiency (+30%) that was obtained by higher performance of the clinics and lower costs of maintenance.

Keywords: Clinics, Facilities Management, Information Technology, Performance-Based-Maintenance.

1. INTRODUCTION

One of the most essential assets available to healthcare organizations is the built-assets, their locations, designation, performance and strategic maintenance and performance management. The facilities available to the community healthcare system create the capability for healthcare services provision, and are crucial in their effect on the quality healthcare services provided. The investment in the development of new facilities as well as in the maintenance of the healthcare facilities accounts for 3-4% of the annual turnover of the sick funds in Israel (Shohet and Lavy, 2004). In the past, design, construction, and operation and management of the buildings was carried out along short term guidelines. Global trends such as increasing in-patient admission and shortening of the duration of stay at hospitals drive healthcare organizations to seek for alternative ways of healthcare delivery schemes amongst them are delivery of healthcare through community clinics (Lavy and Shohet, 2007). These trends cause intensive service conditions at community clinics that are represented by high number of patients and visitors (Shohet, 2010).

Healthcare facilities quality and sustainability are a crucial factor for the quality of healthcare services provision quality. Despite this, in most Healthcare organizations Facility Managers are not part of the strategic core of decision making (Gelnay, 2002). Payne and Rees (1999) figured out that the involvement of Facility Managers in the Healthcare organizations is indispensable for the effectiveness of healthcare services. Gallaguer (1998) discovered seven significant key Success Factors associated with success of the NHS (National Health Service) FM among them are *strategic maintenance planning* and *maintenance benchmarking*. Andaleeb (1998) figured out five key factors associated with the satisfaction of healthcare services consumers among them is the Quality of healthcare facilities. Progress in the understanding of Healthcare facilities Key Performance indicators in the past two decades led to development of Computer Aided decision analysis tools (Lavy and Shohet, 2007b) and recently to facility information management systems (Lucas et al. 2013). These trends are expected to expedite the implementation of BIM models in healthcare FM (Eastman et al. 2008).

Research in the infrastructure industry (Damnjanovic and Zhang. 2008) and in the manufacturing industry (Ashayeri, 2007) teaches that an integration of building information model with ERP system for performance based-maintenance attains potential economic advantages as well as innovative maintenance methods.

2. HYPOTHESES, OBJECTIVES AND MEHOD OF THE RESERACH

2.1. Research hypotheses

(a) Using Key Performance Indicators (KPIs) based on performance and on Life Cycle Costs (LCC) principles, the maintenance and performance and effectiveness of clinics can be systematically monitored with a high degree of accuracy and reliability; (b) Implementation by clinics of the above-mentioned principles using integrated ERP system can contribute both to savings in their maintenance expenditure and to improved performance. A performance-based model was developed for clinic facilities

2.2. Research method

The objectives of the study were as follows:

A. Development and adaptation of Key Performance indicators Database for clinics facilities maintenance and performance management that will be supported by Life Cycle Costs principles.

B. Establishment of a Decision Making database for ERP system for community clinics that will be used for *strategic maintenance and performance management*.

C. Implementation of the developed system in community clinics, validation, and introduction of further research.

2.3. Research method

The research was carried out through the following stages:

I - Literature review of clinics facilities maintenance and performance management;

II - Development and adaptation of Key Performance Indicators for clinics, KPIs that were used originally for hospital facilities were adapted here for clinics using Life Cycle Costs principles and parameters attributed particularly for clinics facilities;

III - Questionnaire for field data gathering;

IV - Field survey phase I: preliminary data gathering and clinics profiling

V - Setting corrective maintenance and performance management policy, using the inference engine of the ERP system

VI - Implementation of corrective maintenance policy using decision criteria that are sustained by the KPIs, particularly Building Performance Indicator (BPI), Maintenance Efficiency Indicator, and the Normalized Annual Maintenance Expenditure.

VII – Field survey phase II implementation of corrective strategy and validation;

VIII - Validation of the proposed model by implementation of a corrective maintenance policy according to the model diagnosis.

3. THE PERFORMANCE AND MAINTENANCE MODEL

3.1. Key Performance Indicators

The following Key Performance Indicators were adapted for clinics performance and maintenance management:

1. Age coefficient (AC_y);
2. Clinic's patients Density Coefficient (DC_y);
3. Building Performance Indicator (BPI);
4. Annual Maintenance Expenditure (AME);
5. Normalized Annual Maintenance Expenditure (NAME);
6. Maintenance Efficiency Indicator (MEI);
7. Maintenance Sources Ratio (MSR);
8. Managerial Span of Control (MSC);

The following paragraphs briefly describe the guiding principles, hypothesis behind the KPIs that follow.

3.2 Age Coefficient

The age coefficient is defined as a coefficient for the adjustment of maintenance needs to actual service life of the facility. It is described in details in Lavy and Shohet 2007a. It is computed with the following equation:

$$AME_Y = \sum_{n=1}^{10}\left[\sum_{j=1}^{m}\left(M_{nj} + R_{nj}\right)\right] \quad \forall y = 1,2,3,...,50 \qquad [1]$$

Where,

AMEy – Annual Maintenance Expenditure for year y

n – counter of building systems;

j – index of Component in system n;

m – Total number of components j in system n;

Mnj – Annual maintenance costs of component j in system n [$/sq. m.];

Rnj – Costs of component j in system n [$/sq m.];

y – Counter of year along the building service life.

$$AME_{ave.} = \frac{\sum_{y=1}^{50} AME_y}{50} \qquad [2]$$

Where,

AMEave. – Average Annual Maintenance Expenditure along the clinic service life (50 years) in \$/sq. m.;

AMEy – Total annual maintenance expenditure for year y;

y – Counter of years along the building service life;

$$AC_y = \frac{\sum_{y-4}^{y+4} AME_Y + \frac{1}{2}\left(AME_{y-5} + AME_{y+5}\right)}{10 * AME_{ave.}} \qquad [3]$$

$$\forall y = 6,7,8,...,50$$

Where,

ACy – Age Coefficient for year y;

AME_y – Total annual maintenance expenditure for year y [\$/sq.];

$AME_{ave.}$ – Average Annual Maintenance Expenditure along the clinic service life [\$/sq. m.];

Figure 1 depicts the age coefficient of a clinic facility for a designed life cycle of 50 years. It can be seen that the AC is below 1 until the clinic reaches the age of 17 and its highest value is 1/6 at the age of 28 years.

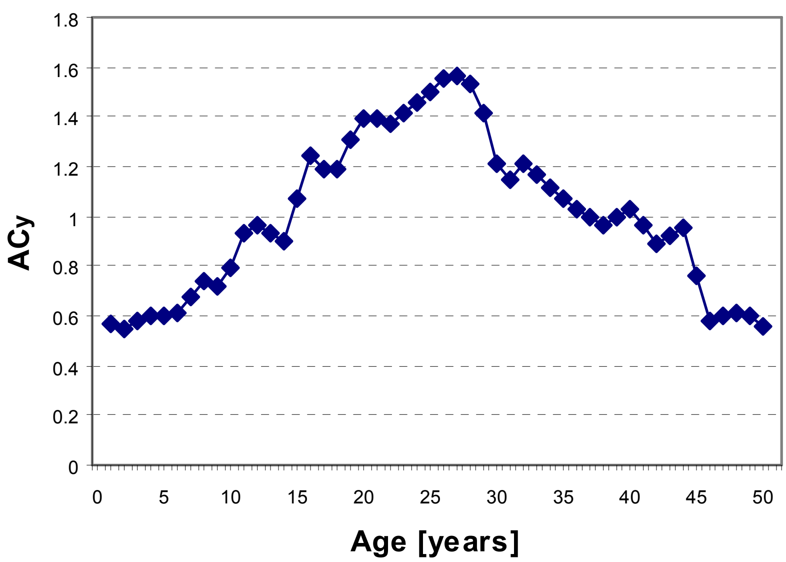

Figure 1: Age Coefficient of clinic facility vs. age of the building

3.3 Clinic's Density Coefficient

The Density Coefficient quantifies the effect of density of patients in the clinic on the deterioration of building components. Standard density was defined as 175 patients per sq. m. per annum and is referenced as 100% density of patients. The research hypothesis is that density conditions affect the deterioration pattern of building components and systems. The Coefficient was developed on the strength of analysis of the life cycle of building components under intensive and under moderate service conditions. The results figured out the following (figure 2):

a. In moderate density conditions (less or equal to 80% of the standard density) the density coefficient equals 0.97 expressing only minor savings in the maintenance activities, due to compulsory preventive policy.

b. Between 80% and 100% relative density – the increase in maintenance activities is moderately linear with a slope of 0.001625;

c. Between 100% and 154% relative density, there is a greater impact to patients' density on the maintenance expenditure, the slope of the graph increases to 0.00578, and the density coefficient in high density conditions remains constant at level of 1.31.

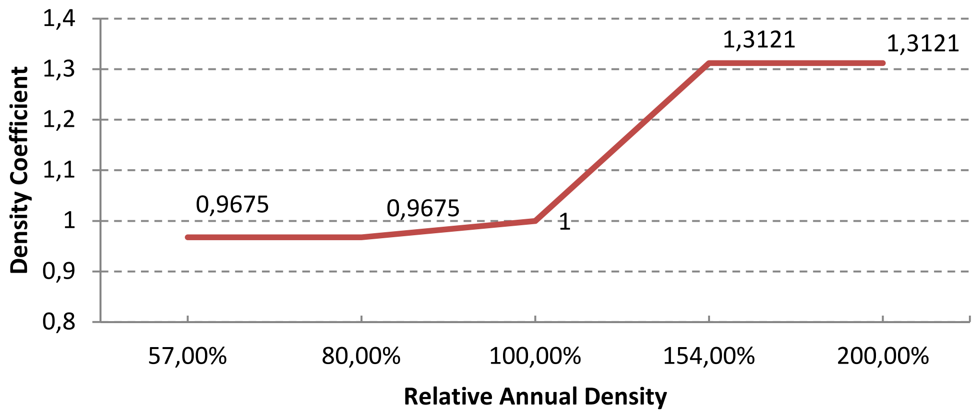

Figure 2: Density Coefficient Vs. Relative annual Occupancy

3.4 Building Performance Indicator (BPI)

This parameter enables the evaluation of the overall state of a clinic or of a clinic portfolio, according to the performance of its components and systems. The indicator is defined by a value, between 0 and 100, that expresses the clinic's performance state. P_n is graded according to performance scales between 0 and 100, where $P_n<60$ indicates poor/dangerous performance condition, $60<P_n\leq70$ indicates deteriorating performance condition, $70<P_n\leq80$ indicates marginal (70) or satisfactory (80) condition, and $P_n>80$ indicates good condition. The actual score for each system (p_n) is expressed by equation [4]. It is composed of three aspects of facility maintenance: (1) actual condition of the system (C_n); (2) failures affecting the service provided by the system (F_n); and (3) actual preventive activities carried out on the system to maintain acceptable service level (PM_n) .

$$P_n = C_n * W(C)_n + F_n * W(F)_n + PM_n * W(pm)_n \qquad [4]$$

Where,

$W(C)_n$ – weight of component condition of system *n*

$W(F)_n$ – weight of failures in system *n*

$W(pm)_n$ – weight of preventive maintenance for system *n*

For every system *n*, the sum $W(C)_{n,}$+$W(F)_n$+ $W(pm)_n$ equals 1.

The score C_n is evaluated on the strength of 100 point rating scale where 100 expresses complete performance score, 60 deteriorating, and 40 and 20 failure and poor performance respectively. The Preventive Maintenance is evaluated on the basis of maintenance policy governing the component, and the frequency of pro-active inspections carried out with respect to standards. Frequency of failures is evaluated on a scale between 100 - no failure in 12 months, and 20 – frequent occurrence (e.g. 12 times in the last 12 months in a roofing system). The combination of these three elements produces the performance score of the entire system (P_n). Weighting of each building system (W_n) in the BPI is accomplished by weighing the contributions of the system's components to the Life Cycle Costs. Table 1 presents weightings of clinics building systems. It is shown that the Interior finishing system consumes 24.4% of the clinic's life cycle costs, the structure accounts for 15.5%, the exterior envelope accounts for 12.1, and HVAC system 10.5%. The profile of this breakdown emphasizes that the interior finishing and the electro-mechanical systems of clinics account for 63% of the entire BPI. The method is described in details in Shohet (2002).

Once the systems' functional states have been diagnosed, the BPI is calculated. The BPI is obtained for each system by multiplying its weight by its score (Equation 5).

$$BPI = \sum_{n=1}^{10} P_n \cdot W_n \qquad [5]$$

The desired BPI range is BPI>80, nevertheless, any system or component at performance score below 70 requires corrective maintenance measures.

This KPI enables to assess the overall state of a clinic; to assess the state of the clinic's systems; to benchmark the asset's performance in relation to other clinics or facilities (inter-organizational benchmarking), and to benchmark the clinic's systems in order to compare the efficiency of the various maintenance crews (intra-organizational benchmarking).

3.5 Annual Maintenance Expenditure (AME)

This parameter reflects the scope of expenditure per sq. m. built (excluding cleaning, energy, and security expenditures). This KPI enables to assess the overall investment in maintenance from an organizational point of view and can be later assessed from a performance-engineering point of view be evaluated with respect to the clinics age and density as described below.

3.6 Maintenance Efficiency Indicator (MEI)

This indicator enables to assess the investment in maintenance with respect to the clinic's performance. The MEI is calculated by equation [6]:

$$MEI = \frac{AME}{ACy} * \frac{1}{BPI} * \frac{1}{DC} * i_c \qquad [6]$$

Where, AME is the actual Annual Maintenance Expenditure, AC_y is the Age Coefficient for year y, BPI is the monitored Building Performance Indicator, DC is the Density Coefficient for the clinic in question, and i_c is the construction prices index.

This indicator expresses the expenditure on maintenance per clinic performance unit, normalized using the Age Coefficient (AC_y) and Density Coefficient (DC).

MEI may be analyzed in two dimensional space of BPI and the Normalized annual Maintenance Expenditure (NAME) as expressed in equation [7]:

$$NAME = \frac{AME}{AC_y * DC_y} \qquad [7]$$

NAME expresses the Annual Maintenance Expenditure neutralized from the effect of age (AC_y), and clinic's patients' density (DC_y).

For a clinic maintained at desired level, we assume a BPI of 100. The average Annual Maintenance Expenditure (AME) per sq m. was analyzed to be 2.50% of the reinstatement value of a clinic facility which was calculated to be $1,180 per sq. m. built. Assuming a facility with an Age Coefficient of 1.00 (the standard), and a Density Coefficient of 1.00 would yield a MEI value of 0.30. The upper and the lower value of the desirable range were deduced from the Standard Deviation of the MEI for the clinic sample population. The MEI values are thus interpreted according to the following categories:

– MEI<0.20 indicates high efficiency with which the resources are utilized, or scarcity of resources for maintenance, or both;

– 0.40≥MEI≥0.20 reflects a reasonable range of maintenance efficiency, in which the lower limit indicates good efficiency while the upper limit indicates low efficiency and/or slack of resources; and

– MEI>0.40 indicates high inputs relative to the actual performance. That may be caused by high maintenance expenditures, low physical performance, or a combination of these two extreme situations.

3.7 Managerial Span of Control (MSC)

This indicator is defined as the number of subordinates reporting to a given supervisor. It reflects the scope of managerial resources invested in the FM department. The MSC expresses the number of employees who are directly subordinate to the manager. It was found in a previous study of MSC in the construction industry (Lavy and Shohet, 2007b) that the span of control affects the way managers divide their time and consequently the performance of the organization.. The desired span of control at the head of organization level is no greater than six, while at the Maintenance Manager's level the desired span of control is eight subordinates.

3.8 Maintenance Sources Ratio (MSR)

This KPI reflects the mix of internal and external maintenance resources, and expresses the extent of outsourcing (in %) out of the total labor resources allocated for maintenance of the facility. Previous studies figured out that outsourcing may contribute to savings of a.c. 10% compared to in-house provision (Domberger and Jensen, 1997; Shohet 2003; Shohet et al. 2003)

3.9 Architecture of the ERP System

The Decision Analysis of the ERP system is composed of three modules: Input interface, inference Engine, and Output interface, (Figure 3). The input data base includes clinics facility data (history of maintenance, Building information data, organizational, costs and performance data). A profile of the facility is developed in the system data basis using the KPIS of clinics described above and the facility is characterized according to its performance, maintenance efficiency, and services provided (outsourcing-in-house).

The inference process of the facility is carried out along the following phases: clinics are classified according to 4 categories of performance (High, standards, marginal, and poor) and 3 categories of efficiency (High, standard-normative, and low). According to the clinic's maintenance efficiency and performance decisions and maintenance policy setting is established. The inference engine combines effectiveness-performance data with organizational parameters (MSC, NAME, and AME) so as to allocate resources and set the performance target. The inference engine follows 7 stages of diagnosis and analysis:

1. Effects of the clinics service condition (Age and density)
2. Diagnosis of prevailing performance conditions;
3. Actual and Normalized Annual Maintenance Expenditure;
4. Performance Cost-Effectiveness of the maintenance;
5. Managerial Effectiveness;
6. Resources management analysis;
7. Corrective maintenance policy setting.

4. IMPLEMENTATION AND VALIDATION

The System was implemented and tested in a two=phase study in clinics facilities. The number of clinics participated in the study was 47 in the first phase and 42 in the second phase. Following the first stage, a corrective strategic policy was established to improve the MEI mainly through systems maintenance and cost-effectiveness. The results were analyzed in the following phase. The overall performance was improved by 4 BPI points, while the overall cost was reduced by 27%. This was achieved by allocation of resources according to cost effectiveness of MEI. The rest of the KPI were not significantly different. The overall effectiveness of resources was measured to improve by 30%, this reflects the improvement in the performance as well as the effect of age (increased between the two phases).

KPI	Phase I (n=47)	Phase II (n=42)
BPI	91.6	95.5
AME [$/sq. m]	33.2	24.20
NAME [$/sq. m.]	36.20	25.01
MEI	0.40	0.30
MSC	7.3	6.1
DC	1.31	1.31
AC_y	0.70	0.74

Table 1: KPIs of clinics facilities in the study

5. CONCLUSION AND DISCUSSION

A theoretic-scientific infrastructure was laid down for the development of Enterprise Resource Planning system for maintenance of clinics facilities. A framework of KPIs was developed and established that allows for clinics facilities development performance management, maintenance and supply chain management. A 3-module ERP system was developed that follows three-phase reasoning process:

- Analysis of the Clinics Performance
- Maintenance efficiency analysis
- Derivation of maintenance policy at facility and systems level

The proposed ERP system is generic as it follows three principles of reasoning: performance benchmarking, adaptation of the expenditures on maintenance to effects of age, and other service conditions such as the density of patients, and benchmarking of efficiency of maintenance. Implementing of the above principles in a two-phase pilot study was used to validate the system. The pilot study findings showed an improvement of 30% in efficiency of resources for maintenance of clinics. The performance of the clinics was improved as well. The study confirms that the potential attained in ERP systems for clinics facilities is high and that this route of development may contribute to better facilities performance and higher cost-effectiveness.

The results of this pilot are supported by other studies on Performance-Based-Maintenance in public office and residential buildings that achieved similar results (Straub, 2007, 2009a, 2009b; Shohet and Straub, 2013).

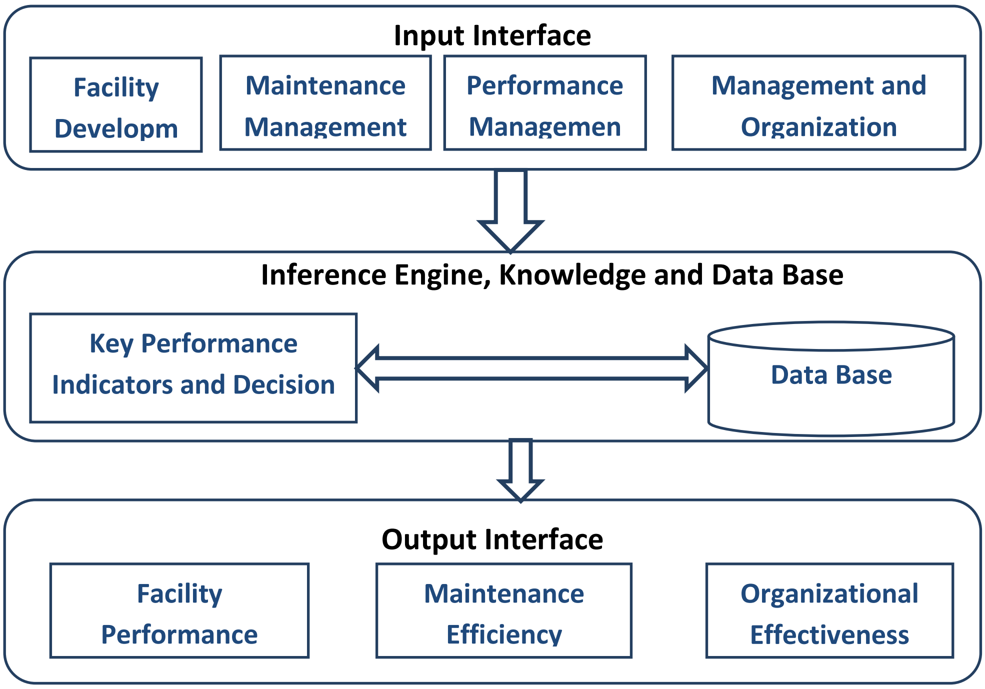

Figure 3: Architecture of Clinics Facilities ERP system

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EVALUATION OF DEMOLITION WASTES FOR USE IN ROAD BASES AND SUB-BASES CONSTRUCTION IN QATAR

Okan Sirin
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar okansirin@qu.edu.qa

Ramzi Taha
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar ramzitaha@qu.edu.qa

Rabah Qunnaby
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar rab9993@qu.edu.qa

Khalid Alkhamis
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar 200702564@qu.edu.qa

Mohammad Naser
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar mn1000949@qu.edu.qa

Mohammad Younis
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar my1002058@qu.edu.qa

Abdullah Shihadeh
Qatar University,Dept. of Civil & Architectural Eng., Doha, Qatar as1002410@qu.edu.qa

Abstract

Large quantities of waste materials (around 20 million tons per year) from building and construction wastes and demolition rubble are being generated due to the construction boom in Qatar. As the amount of waste materials increases, it will be difficult to safely dispose such materials in landfills. In order to provide a sustainable environment for future generations, alternative solutions of utilizing these waste materials are needed. The main objective of this paper is to investigate the feasibility of using waste materials in the construction of road bases and sub-bases. In this study, reclaimed asphalt pavement (RAP) aggregates and excavation waste (EW) materials obtained from road and building construction projects in Qatar were evaluated. Different combinations of such materials were prepared and subjected to a series of tests in accordance with Qatar's Construction Specifications (QCS) to determine their physical and mechanical properties. Results indicate a weak potential for using RAP aggregates, EW materials, or a combination of the two in road bases and sub-bases. However, these materials need to be investigated further to be utilized in other construction applications.

Keywords: demolition wastes, recycling, road bases and sub-bases, sustainability.

1. INTRODUCTION

1.1 Background

Waste materials are commonly used in construction projects in order to save natural resources for future generations. Pavement construction is one of the main users of these natural resources. Utilizing these materials in base/sub-base construction will provide sustainable development in a country by saving virgin materials, conserving energy and diverting materials from landfills [Horvath, 2003].

Recycled materials used in asphalt pavements and base/sub-base applications mainly come from construction and demolition wastes (CDW), solid wastes (SW) and by-products from industrial processes. Most commonly used ones include coarse and fine aggregates, tiles, bricks obtained from CDW and excavation wastes (EW) , reclaimed asphalt pavement (RAP), incinerator bottom ash (IBA), crumb rubber, fly ash, plastics and glass [El-Assaly and Ellis, 2001].

Demolition Waste is the material that is generated due to the destruction of a structure, specifically reinforced concrete structures, or generally a structure/object that contains sand and concrete as shown in Figure 1.

Figure 1: Demolition Rubble of a Concrete Building

In some countries where aggregate and sand resources are limited, these wastes are usually recycled and harvested for other construction purposes. The amount of CDW generated in some European countries in 2006 can be seen in Figure 2.

Another source of wastes that could be recycled for construction use is the waste materials generated from the ground excavation process. These materials are formed due to excavation work during the construction phase of a structure, underground infrastructure and metro stations.

The material usually consists of natural soils from the excavated locations and; it might also contain other materials like wood and organic material. In Qatar, particularly, excavation wastes mainly consist of crushed aggregates and sand and are usually dumped at the outskirts of Doha.

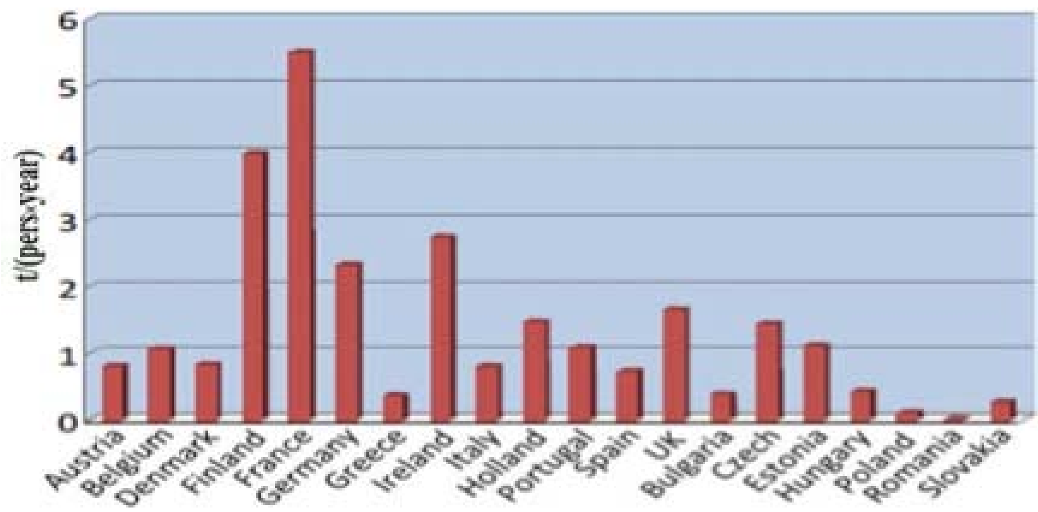

Figure 2: Quantities of generated CDW in some European countries in 2006 (Source: Muscalu and Andrei, 2011)

Reclaimed Asphalt Pavement (RAP) is another waste material generated when asphalt pavements are removed for reconstruction and resurfacing. They are commonly used in hot-mix asphalt courses and base/subbase applications as well [Kallas, 1984; Decker and Young, 1996]. Table 1 shows the quantities of RAP generated in various countries in the world.

Table 1: Quantities of RAP generated in some countries (Source: Data obtained from the literature)

Country	RAP Generated, million tons per year (in 2008)
United States	73
United Kingdom	2
Sweden	0.84
Germany	0.73
Denmark	0.53
Japan	20

Recycled excavation and demolition wastes both have numerous applications in the construction industry, particularly in the base and sub-base layers of roads and pavements. They are also used in the construction of pedestrian pavements and buildings.

Economic, industrial and population growth in Qatar will generate increasing amounts of waste materials that must be disposed of. As the volume of wastes continues to grow, the approval and availability of facilities for waste processing and proper disposal will become more difficult to obtain. In addition, Qatar suffers from the availability of quality aggregates and materials that could be utilized in road, parking and building construction. Most of the aggregate used in the country is imported from the United Arab Emirates and other neighboring countries, thereby, increasing construction costs and probably causing unnecessary project delays. It is estimated that approximately 15 million tons of aggregate are imported every year. Qatar generates large quantities of building and construction wastes including milled asphalt pavements and demolition rubble (close to 20 million tons a year), which could be recycled in road construction.

1.2 Objectives

Reclaimed asphalt pavement and excavation wastes that are commonly found in piles around various locations in Qatar could be recycled and used in the bases and sub-bases of roads, thus saving resources and protecting the natural environment of Qatar. The main objective of this study was to investigate the feasibility of RAP material, EW and various combinations of these two materials to be used in road base/sub-bases according to Qatar Construction Specifications (QCS 2010).

2. MATERIALS

A total of three waste materials namely Excavation Waste-1, Excavation Waste-2 and RAP were collected from several locations around Doha. Stockpiles of excavation waste materials and RAP used in this study can be seen in Figures 3 and 4, respectively.

Figure 3: Picture of an EW stockpile Figure 4: Picture of a RAP stockpile

A total of 25 buckets for each type of waste material were sampled from stockpiles and brought to our construction materials laboratory for physical and mechanical testing. The following tests were conducted on the three waste materials and results were compared against QCS 2010.

1. Sieve analysis (ASTM C 136)

2. Density, bulk specific gravity and absorption of coarse and fine aggregates (ASTM C 127 and ASTM C 128)

3. Los Angeles (LA) abrasion test (ASTM C 131)

4. Sand equivalency test (ASTM D 2419)

5. Liquid limit and plasticity index tests (BS 1377)

6. Standard Proctor compaction test (ASTM D 698)

7. California Bearing Ratio (CBR) test (ASTM D 1883)

3. TEST RESULTS AND DISCUSSION

3.1. Physical tests

Physical properties of the three materials were determined in the laboratory. Summary of test results for course and fine aggregates can be seen in Tables 2 and 3, respectively. Table 2 indicates that all three materials did not meet the maximum 40% LA Abrasion criteria specified in QCS 2010. However, the LA abrasion value for the RAP material was slightly higher than that of the QCS 2010 requirement.

Table 2: Physical properties of coarse aggregates

Property	Sp. Gravity	Absorption %	Bulk Den. (kg/m^3)	L.A Abrasion
EW-1	2.217	8.74	1501	50.08 %
EW-2	2.466	6.57	1665.2	60.30 %*
RAP	2.41	2.35	1691.5*	43.10 %*
QCS 2010	N/A	N/A	N/A	≤40 %

* Average of two readings N/A: Typical values are not mentioned in QCS

Table 3 shows that liquid limit and plasticity index requirements for all three materials were not met according to QCS 2010. However, sand equivalency for EW-2 and RAP material were satisfactory. The sand equivalency value for EW-1 was slightly less than the QCS 2010 criteria of a minimum of 25 %.

Table 3: Physical properties of fine aggregates

Property	Specific Gravity	Absorption %	Bulk Den. (kg/m^3)	Sand Equivalent	Liquid limit	Plasticity Index
EW-1	2.15	11.8	1569.5	23%	39.2%	12%
EW-2	2.284	12.4	1225.1	29%*	48%	20.1%
RAP	2.01	1.2	1487.4*	96%*	-	-
QCS 2010	N/A	N/A	N/A	≥25%	≤25%	≤6%

* Average of two readings N/A: Typical values are not mentioned in QCS

In order to determine the grain size distribution of materials collected from the field, sample sizes were screened using a splitter to collect enough material to run the sieve analysis test according to ASTM C 136. Figure 5 shows the sieve analysis results for EW-1 along with the upper and lower limits for Class A (base course) given in QCS 2010. It can be seen from the figure that % passing amount for some sieve sizes are outside the upper and lower limits and, thus do not meet the specification requirement.

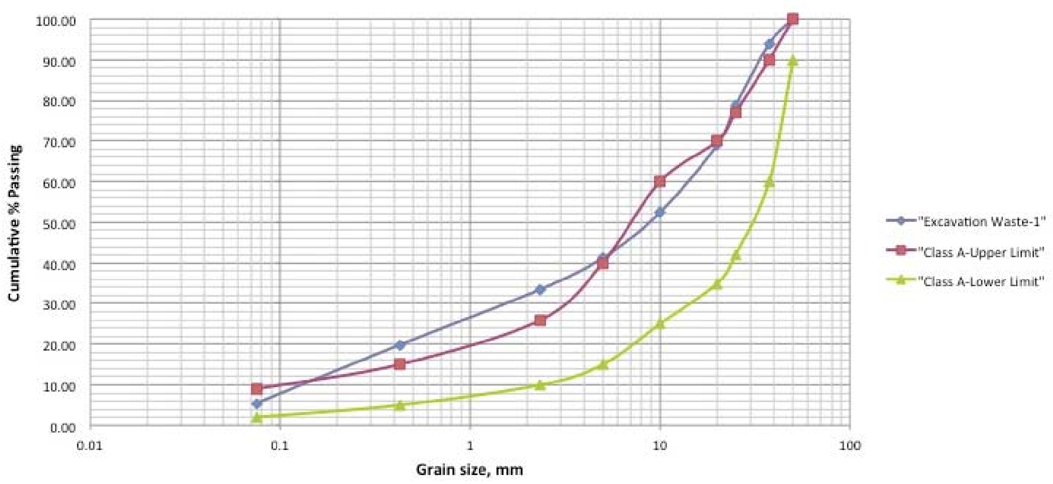

Figure 5: Sieve analysis results for Excavation Waste-1

All sieve analysis results for three materials and % passing requirements for three types of bases and sub-bases (Classes A, B and C), given in QCS 2010, are tabulated in Table 4. Results indicate that EW-1 and EW-2 materials can meet the requirements for a Class B type base course but not for Classes A and C. However, RAP material did not meet the % passing requirement for any type of typical base courses given in QCS 2010.

Table 4: Sieve analysis results and gradation limits in QCS 2010

Sieve size (mm)	Percent Passing					
	Excavation Waste-1	Excavation Waste-2	RAP	Class A (QCS 2010)	Class B (QCS 2010)	Class C (QCS 2010)
50	100	100	100	90-100	100	-
37.5	93.9	85.2	100	60-90	70-100	-
25	78.7	77.8	98.2	42-77	55-85	100
20	69.1	70.5	95.2	35-70	50-80	90-100
10	52.4	53.0	64.5	25-60	40-70	50-85
5	41.2	40.2	22.2	15-40	30-60	35-65
2.36	33.6	32.5	7.0	10-26	20-50	25-50
0.425	19.8	19.0	0.6	5-15	10-30	15-30
0.075	5.5	5.3	0.13	2-9	5-15	5-15

3.2. Mechanical Testings

3.2.1. California Bearing Ratio (CBR) Test

3.2.1.1. Optimum Moisture Content

Laboratory compaction tests are usually used for determining the percent compaction and optimum water content needed for a dense mix. For this purpose, different amounts of water were added to sample mixes to determine the optimum moisture content (OMC) using the standard proctor compaction Test (ASTM D 698). Samples were compacted by 25 blows in 3 layers using a 24.5 N rammer dropped from a height of 305 mm. Corrected moisture contents were determined after drying samples at an oven temperature of 110±5 °C for 24 hours. A total of 21 sample mixes were prepared using different percentages of EW-1, EW-2 and RAP materials. Sample combinations were prepared using different percentages of two materials (RAP+EW-1 and RAP+EW-2).

The compaction curves for each sample were established after a sufficient number of water contents were used. The relationship between the dry unit weight and water content for some samples are shown in Figure 6.

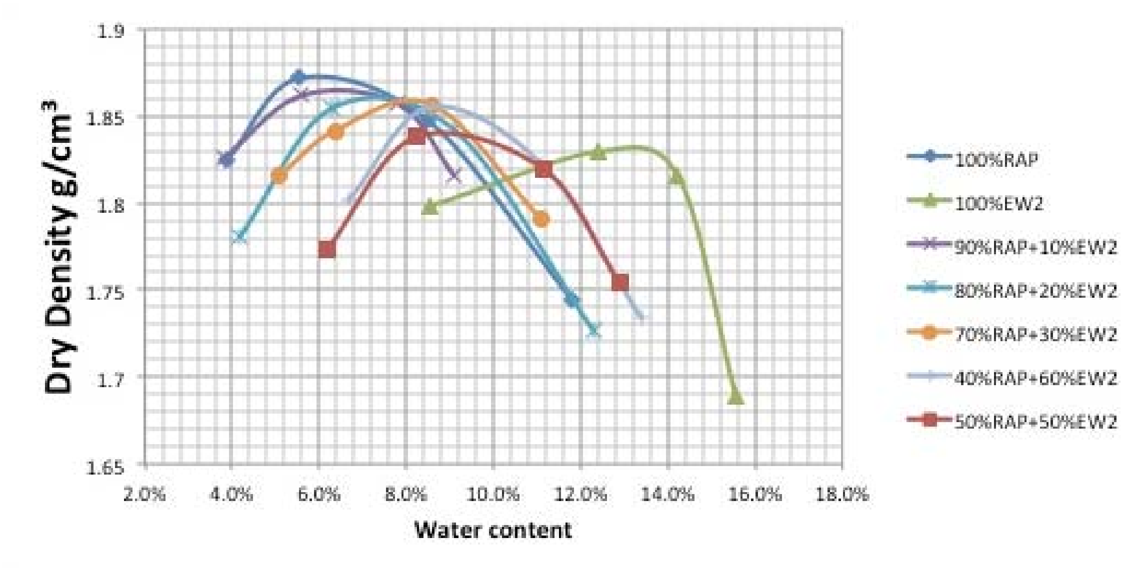

Figure 6: Plots of dry density versus water content for sample mixes

The optimum moisture content (OMC) results for all sample mixes (21 in total) are summarized in Table 5. Results indicate that % OMC decreases with a decrease in EW-1 and EW-2 content in the sample mix. This is due to the absorptive nature of excavation waste materials in comparison with the RAP material.

Table 5: Optimum Moisture Content (OMC) results for all sample combinations

Sample	% RAP	% EW-1	OMC (%)	Sample	% RAP	% EW-2	OMC (%)
1	0	100	13.9	**12**	0	100	13.7
2	10	90	13.6	**13**	10	90	13.4
3	20	80	12.5	**14**	20	80	12.9
4	30	70	12.7	**15**	30	70	13.1
5	40	60	10.1	**16**	40	60	10.1
6	50	50	9.6	**17**	50	50	9.8
7	60	40	9.1	**18**	60	40	9.1
8	70	30	9.0	**19**	70	30	8.3
9	80	20	7.9	**20**	80	20	7.9
10	90	10	6.4	**21**	90	10	6.8
11	100	0	5.8				

3.2.1.2. CBR Results

Samples were compacted at the OMC in accordance with ASTM D 698 (standard proctor compaction test). Then, compacted samples were soaked in water for 96 hours prior to conducting the California Bearing Ratio (CBR) test (ASTM D 1883). No swelling was observed in the soaked samples. Since the work is still in progress, the CBR results for only 6 samples are provided in Table 6. The data indicates that none of the samples satisfied the minimum

CBR requirement of 80% specified in QCS 2010 for base/sub-base materials. However, there was an increase in CBR with an increase in RAP content in the mixes.

Table 6: CBR results for a variety of sample combinations

Sample No	Sample	CBR (%)
11	100 %RAP	19.3
20	80 %RAP+20%EW-2	17.6
18	60 %RAP+40%EW-2	15.4
16	40 %RAP+60%EW-2	9.7
14	20 %RAP+80%EW-2	7.6
12	100% EW-2	6.1

4. CONCLUSIONS

Excavation waste and RAP materials collected from different locations in Qatar were investigated for possible use in road base and sub-bases in the State of Qatar. Physical and mechanical tests were conducted on a variety of sample combinations to determine their suitability according to QCS 2010. Base on the data obtained from laboratory testing, following conclusions can be made:

– All three materials did not satisfy Los Angeles abrasion and CBR criteria for unbound materials given in QCS 2010.

– Based on the limited data obtained in this study, EW-1, EW-2 and RAP materials do not seem to be appropriate for road bases and sub-bases in the State of Qatar.

– For a future study, all three materials could be blended with different waste or virgin materials or stabilized using cementitious additives for eventual use in road construction applications.

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BIM & PROJECT COST MANAGEMENT – IMPLEMENTATION ISSUES & CREATIVE SOLUTIONS

Dr. Peter Smith
University of Technology Sydney, Sydney, Australia, peter.smith@uts.edu.au

Abstract

This paper examines the issues related to the implementation of Building Information Modeling (BIM) and Automated Quantities technologies by the Australian Quantity Surveying profession. The findings provide lessons learnt and solutions that are relevant to the project cost management field on a global scale.

Objectives of Study: The effective implementation and use of BIM and automated quantities remains a major issue for the QS profession in Australia as it does for the construction industry generally. The purpose of this study is to investigate the main barriers and problems facing firms and, conversely, to identify approaches that are being successfully used by firms that are leading the way in the field.

Methods: The methodology for this paper is based on a review of current industry trends and issues with BIM implementation, detailed interviews with quantity surveying firms in Australia to evaluate how the profession is dealing with BIM implementation and a case study of a quantity surveying at the forefront of BIM implementation.

Results: The interviews reveal that there are considerable implementation issues. The key problem relates to quality issues with BIM models – the industry requires high quality BIM models for all professionals to be able to use the model most effectively and, more importantly, trust the accuracy of the information and data that is being generated. Liability issues for incorrect information/data generated from the models were also highlighted as a major area that needs addressing. Nevertheless, an increasing number of firms are utilizing 5D BIM tools to dramatically improve the quality, efficiency and sophistication of their cost management services particularly at the front end of projects at the cost planning stage.

Conclusions: The paper concludes with a range of creative solutions and recommendations based on the case study results and other innovative approaches adopted by the interviewed firms.

Keywords: BIM, project cost management, 5D BIM.

1. INTRODUCTION

Building Information Modeling (BIM) and automated quantities technologies provide both enormous opportunities and challenges for the project cost management profession. As quantification increasingly becomes automated and BIM models develop the role of the project cost manager will need to adapt accordingly to provide more sophisticated cost management services that incorporate 4D time and 5D cost modelling and sharing cost information/data with the project team as part of the BIM integrated project delivery approach. The implementation of Building Information Modeling (BIM) on construction projects is gaining momentum around many parts of the globe. Whilst the technology underpinning BIM has been around for well over a decade BIM implementation and take-up has been relatively slow in the construction industry compared to industries such as manufacturing and engineering. This is starting to change as building proprietors and government entities increasingly become a driving force for the adoption of BIM by mandating its use on their projects and the technology and implementation issues continue to improve.

This paper will commence with a review of current BIM implementation trends and issues in the construction industry both within Australia and globally and will then focus on the issues for the quantity surveying profession in Australia. The latter will be based on detailed interviews with Australian Quantity Surveying firms. This will then be compared with a case study of innovative BIM approaches being used by a leading quantity surveying firm in the field.

2. LITERATURE REVIEW

2.1. Global BIM Implementation Trends

North America and the Scandinavian regions are generally regarded as the construction industry leaders in BIM development and implementation (Wong et al. 2009). McGraw Hill Construction (2013) found that BIM adoption by project team professionals in the North American industry had grown from 17% in 2007 to 71% in 2012 which demonstrates that BIM is now in the mainstream in the industry. This indicates that this region is leading the way on a global scale.

The Scandinavian region also has a strong BIM development and implementation track record. Government mandates for the use of BIM on government projects have provided further impetus in countries such as Finland, Norway, and Denmark. The Finnish Government have invested heavily in IT research in the construction industry since the 1970s (Granholm 2011). They recently released a Universal BIM Guide for the industry which is being heavily supported. The Finnish public sector is the key driver in BIM adoption with Senate Properties, a major government entity with a property asset portfolio of approximately 6 billion Euros, a major leader requiring BIM on their projects and undertaking many pilot and research projects. Across the industry BIM is used on 20-30% of government projects with predictions that this will increase in the near future to 50% (Koppinen & Henttinen 2012). In Denmark the Danish Enterprise and Construction Authority established a Digital Construction Program in 2007 that has been implemented by major government entities. The program requires that BIM is used on all projects over 5.5 million Euros with information exchanged using the Industry Foundation Class (IFC) format. A number of reports and guidelines have been produced to assist firms in meeting these requirements (Building Smart 2012). In Norway Statsbygg is the Norwegian government's construction and project management representative and requires the use of BIM on all public projects. The Norwegian government is a strong supporter of BIM and invests heavily in research and development (Granholm 2011).

Singapore is also emerging as a world leader in BIM implementation. The Singapore Building and Construction Authority (BCA) have developed a strategy to have BIM widely implemented on public projects by 2015 (Granholm 2011). The government has also established a Construction Productivity and Capability Fund (CPCF) of S$250 million with BIM a key target. In 2000 the Construction and Real Estate Network (CORENET) program was established as a strategic initiative to drive transformation in the industry through the use of information technology. CORENET provides the infrastructure for the exchange of information amongst all project participants. The CORENET e-Plan Check system for development applications is a further initiative to encourage the industry to use BIM. The system enables architects and engineers to check their BIM designed buildings for regulatory compliance through an online 'gateway'. Singapore has adopted the Industry Foundation Classes (IFC) as the standard for BIM implementation (Building Smart 2012).

In the United Kingdom the government has introduced a BIM implementation strategy for the UK construction industry that is considered by many to be the most ambitious and advanced centrally driven BIM implementation program in the world (HM Government 2012). The objective is to transform the UK industry into a global BIM leader in a relatively short space of time (Withers 2012). In May 2011 the UK Government Construction Strategy was published which detailed the government's intention to require BIM on all of its projects by 2016 through a 5 year staged implementation plan. BIM is seen as central to the government's objective in achieving a 20% saving in procurement costs (Cabinet Office 2011). This strategy has had a dramatic impact on the UK industry as firms scramble to develop the necessary technological capabilities to meet these requirements. This strategy has the potential to influence BIM implementation on a wider global scale as other countries take note of these developments.

2.2. BIM Implementation in Australia

In Australia BIM use in the construction industry is not currently widespread and there has not been any government mandates to use BIM on projects of any note. But the past five years has since interest in BIM adoption intensifying as a result of a number of initiatives to engage and inform project stakeholders about the potential productivity gains and gaining competitive advantage (CIBER 2012). These initiatives include the development of Australasian BIM guides such as the 'National BIM Guide' by the National Specification (NATSPEC), 'National Guidelines for Digital Modelling' by the Corporate Research Centre for Construction Innovation (CRC-CI), the 'Australian and New Zealand Revit Standards' (ANZRS) and the BIM-MEPAUS guidelines and models. The 'buildingSmart' organisation (previously called the International Alliance for Interoperability) continue to play a major leading role in BIM development and implementation in Australia that includes establishing an 'Open BIM Alliance of Australia' that involves an alliance with a number of software vendors to promote the concept of 'Open BIM' (CIBER 2012). Building Smart (2012) found that BIM implementation has accelerated markedly in Australia since 2008-09 due to a significant increase in the number of engineering firms adopting BIM thus facilitating multi-disciplinary BIM collaboration (as the larger architectural practices have been using BIM technologies since the late 1990s).

2.3. BIM Implementation Issues in Australia

BIM implementation issues in Australia are not dissimilar to those experienced in other countries. The AIA (2010, p.2) highlight leadership as the key requirement. 'Leadership is required to move the AEC industry forward. Users of BIM are taking different approaches to solving the issues that are presented, and the resulting fragmented approach across the industry has made it difficult to capitalise on the considerable benefits of a coordinated approach based on trust, communication and commitment'. To this end government is widely cited as the key driving force for change and that leadership should stem from that level (CIBER 2012, AIA 2010). The AIA (2010) contend that the Australian federal government should provide the leadership to facilitate a coordinated approach across all state and territory boundaries. The AIA (2010) also emphasised the need for industry and professional associations to be more proactive and to help lead the many changes required in the industry. They developed a series of key recommendations for BIM implementation which also provide insight into the industry issues: Leadership and coordination across the industry with government mandates for BIM use and industry/professional association partnerships to work together; Industry skills development with coordinated approaches to training; Multi-disciplinary approaches to education with universities and colleges providing BIM courses across disciplines and faculties; Software compatibility development ; and Client BIM awareness and education strategies (AIA 2010, p. 12)

3. RESEARCH METHODOLOGY

The literature review revealed that there has not been any current study carried out on the level of BIM adoption and implementation by the quantity surveying profession in Australia. Accordingly the research methodology adopted for this study was to undertake industry interviews with medium to large quantity surveying firms in Australia and to undertake a case study analysis of one quantity surveying firm that is providing innovative leadership in terms of BIM implementation. The quantity surveying firms comprised three medium sized firms (10-20 employees) and three large firms (20 plus employees). All of the firms had affiliated offices in Australia but focus was placed on the quantity surveying services provided by the home office. The firms were located in NSW and Queensland. Four of the firms (the three large firms and one medium sized firm) had experience with the use of BIM and automated quantities whilst the other two firms had limited experience with automated quantities and no experience with BIM on their projects to date. The interviews were conducted individually with experienced quantity surveying practitioners from each of the firms and involved general discussions on the benefits and issues surrounding BIM and automated quantities implementation. The interviews enabled a deeper interrogation and understanding of the issues than might be obtained via questionnaire surveys. The firms represented a good indicative sampling of medium and large sized firms in the Australian quantity surveying profession. The interviews were complemented by an in-depth case study of a medium sized quantity surveying firm that is one of the leading QS proponents of BIM and automated quantities adoption with a reputation for leading edge innovative approaches.

4. RESEARCH RESULTS – INDUSTRY INTERVIEWS

4.1. The Interviews

The interviewees were asked a range of questions relating to the issues, problems and benefits associated with the implementation of BIM and automated quantities. The following provides a summary of the main findings.

4.2. Automated Quantities

All of the firms interviewed used automated quantities software to prepare quantities on their projects. Four of the firms used this software extensively particularly in the cost planning stages whilst the other two firms used such software in a limited capacity. The firms used both proprietary and in-house software with the CostX program the most commonly used program. The CostX program is now the most widely used software of this type in Australia and is now used in over 40 countries around the world (Exactal 2013). The CostX program and the in-house programs were all capable of linking in with BIM models. The firms all agreed that they were on the ‘automated quantities’ path and that this would continue to develop as their own expertise and the software improved. The main issue that they found was in the quality of the electronic documentation (be it 2D, 3D or BIM models). The quality of documentation is critical to the development of accurate quantities and this issue has existed long before the introduction of electronic documentation. In the traditional 2D paper based days interrogation of the drawings and queries to correct design and information errors and inconsistencies was a normal part of the measurement process. The firms stressed that nothing has changed in the new electronic environment. The documentation still needs to be checked for errors and inconsistencies.

The new problem though is that it is more difficult to check the documentation accuracy despite advances in clash detection in BIM models. In the 2D days measurers would spend days and weeks measuring and 'absorbing' the project information in great detail. In the electronic 3D environment far less time is spent measuring and 'absorbing' and understanding the documentation details. There is also a new breed of young quantity surveyors who don't have that solid fundamental training in 2D paper-based measurement and may lack the experience and expertise to identify problems in CAD/BIM models as they might have done in the 2D environment. This leads to the major problem of not trusting the automatic quantities produced due to quality issues with the model. Problems may also occur where quantity surveyors are not fully conversant with the automated quantities software. This requires experience, expertise and intuition to be able to identify problems with the quantities produced.

The firms only use automated quantities to the extent that is feasible – whilst ideally suited to cost planning measurement there are still limitations with more detailed measurement for Bills of Quantities, Builders Quantities and other detailed estimating requirements. Automatic quantities will also only reflect what is detailed in the model – the need to identify information and quantities not in the electronic model is critical. It is also of note that with all of the interviewed firms a considerable amount of measurement is still done via traditional means (i.e. not automated quantities) particularly with respect to detailed measurements for Bills of Quantities and Contract/Claims Administration. All firms saw automated quantities as a 'journey' as they evolve with the technology and use it where practical and useful. They all agreed that there has been a significant increase in the use of automated quantities over the past few years within their firms.

4.3. Quality of the BIM Model

As mentioned with automated quantities, all interviewees cited the quality of BIM models as their major concern. The use of BIM models require the input of vast amounts of interconnected data and information that is typically complex. Whilst BIM models have clash detection facilities there are limitations in terms of checking all information in the model. Clients also need to be prepared to invest in the proper development of a quality model – often the limitations are brought about by consultancy fees that are insufficient to develop the model to the level required. The concept of 'Rubbish In Rubbish Out' certainly holds true for BIM models. The liability for the use of inadequate or incorrect information in the model is also a major concern.

4.4. Business Changes

The move towards BIM capability and expertise requires quantity surveying firms to re-evaluate and re-engineer their business practices. The interviewees all agreed that this is nothing new for quantity surveying firms who have typically had to adapt and rebrand their services to meet the changing demands of clients and the industry generally. A trend has emerged whereby the larger quantity surveying firms are forming alliances with other firms to form global management consultancy practices that provide services well beyond the traditional domain of the quantity surveying practice. Nevertheless the business impacts of moving to BIM and automated quantities are significant. Whilst the software and technology does require significant up-front investment the greatest cost lies in staff training and development. Whilst the aim is for this to reap benefits and competitive advantage in the longer term these development costs are significant particularly in the current climate where market activity in many sectors of Australia are at relatively low levels and fee cost-cutting amongst quantity surveyors and other construction professionals is common-place. Many firms have limited financial scope to invest in current and future digital technologies and capabilities. The added complication is that the technology is always evolving and the interviewees commented that a lot of time and expense can be spent on software and training with uncertain outcomes. The 'pioneering' path can be high risk as firms become 'test pilots' for certain technology whilst their competitors wait in the wings to see if the 'testing' will result in commercial value and competitive advantage. But all interviewees agreed that the 'wait and see' approach is no longer viable for firms that want to be key players in the construction market particularly at the top end.

Cultural business change is another challenge for firms - changing the mind-set of staff to embrace and evolve with this new technology. This is seen by many firms as the significant inhibitor to major change – the conservatism and inability to adapt by staff members. However the interviewees commented that they have noticed clear shifts in attitudes in the past couple of years as professional staff realise that if they do not evolve with this technology and develop expertise they will be left behind. The younger quantity surveying generation moving into the profession are more amenable to digital technologies and change and in many ways represent a threat to more senior personnel resistant to change.

The issue here raised by interviewees was whether this younger QS generation are moving too quickly with this technology without developing fundamental QS competencies and skills. Traditionally young quantity surveyors would spend much of their time physically measuring and 'absorbing' project details and documentation. The more progressive firms are now getting their young QSs to use automated quantities software immediately but there is a question of whether they are moving too fast and are not developing the analytical and checking skills and competencies required to evaluate and critique the information being automatically generated.

4.5. Lack of Standards/Software Incompatibility

All of the interviewees note that the lack of consistent standards and software incompatibility along the project supply chain remains an issue despite great improvements in recent years. Fully integrated project delivery with multi-disciplinary project teams working on a single integrated and compatible BIM model is essential for the optimal use of

BIM. The scope for this currently remains limited. The use of BIM is generally considered to be currently more suited to larger projects with larger clients and contractors who have the scope to demand that all project participants have the necessary technological capability and compatible software. Even then two of the interviewees spoke of working on BIM projects but effectively working outside of the BIM model due to incompatibility issues in terms of not only software but also standards and practices. This is also compounded by key parties in the project supply chain not meeting the capabilities required. All agreed that these issues will continue to improve but nonetheless are critical for successful BIM implantation across the industry.

4.6. Sharing Cost Data Information

The full implementation of BIM on projects involves the sharing of information amongst project participants. A quantity surveying firm’s cost databases provide the foundation for the quality and value of the services they provide and can provide significant competitive advantage. Accordingly the concept of sharing this cost data with the project team is still being addressed by firms. Interviewees all noted that this is an issue not easily resolved but agreed that as BIM becomes more mainstream over time this concept will become a reality for firms – either share their data or not be involved.

4.7. Legal/Contractual/Insurance Issues

The legal and contractual issues relating to BIM projects are still being addressed and create considerable uncertainty for BIM participants. The interviewees agreed that this needs to be resolved before the full collaborative potential of BIM can be realised. This starts with clearly establishing legal ownership of the model and legal responsibility for errors and problems with the model through the whole life cycle of the model. The uncertainty over legal liability is also creating issues for insurers in the industry which has obvious implications for firms providing services on BIM projects. This creates uncertainty over insurance coverage and may lead to insurance exclusion for BIM projects.

4.8. Overall

Overall the interviewees all agreed that the path to BIM is inevitable but the rate of adoption and implementation remains to be seen. At the moment it appears that BIM is more suited to larger projects where the project teams have the requisite capabilities. Government mandates to use BIM on public sector projects would certainly accelerate BIM implementation but the interviewees expressed concern over whether the industry is ready for this and that it could do more harm than good.

5. RESEARCH RESULTS – CASE STUDY

5.1. The Case Study

The research interviews were then augmented by a case study analysis of the quantity surveying firm Mitchell Brandtman - one of the most innovative and progressive QS firms in Australia. The purpose of the case study is to demonstrate what is possible for the quantity surveying profession in the BIM and digital technologies fields and to highlight the visionary approaches being undertaken in relation to the role of the modern day quantity surveyor. This case study is based on correspondence with the firm's Managing Director, David Mitchell, and a variety of information published by the firm and David (Mitchell 2012, Mitchell 2013, Mitchell Brandtman 2013).

5.2. Background to Firm

Mitchell Brandtmann is a medium sized Quantity Surveying firm that was established in 1970. The main office is in Brisbane, Queensland with branches in NSW, Victoria, ACT and regional Queensland. The firm is well known for its innovative approaches particularly with respect to the use of Information Technology (IT). They are leading QS BIM specialists having been involved in the implementation and development of BIM for over a decade. They have a long history of Information Technology (IT) development having commenced their IT journey in 1981. They first began utilising CAD systems in 1997 and soon began working on automated quantities generation testing a number of systems. In 2003 they moved to the CostX automated quantities software system and have been integrally involved in the development and use of this software ever since. This has coincided with extensive research and development in the BIM field to the point where they are one of the leading QS BIM proponents in Australia. This has escalated in the past few years with the firm entrenched in 5D Quantity Surveying BIM practice. They now have a dedicated 5D Team Digital Technologies Manager. The following will outline some of the leading edge and visionary practices and directions of the firm.

5.3. 5D Quantity Surveyors

Mitchell Brandtman market their firm as '5D Quantity Surveyors and BIM Advocates and Specialists'. Mitchell (2012) contends that the modern day QS should be a 5D QS utilising electronic models to provide detailed 5D estimates and living cost plans in real time. Mitchell believes that the QS provides greatest value through their cost planning role at the conceptual front end stages of a project by providing cost advice and estimates on various design proposals and then refining those estimates as the design evolves. Using traditional 2D approaches this cost planning advice takes considerable time and inhibits rigorous comparative analysis within the allocated time frame for the design development process.

However Mitchell argues that the '5D QS can do this extremely quickly, an endless number of times and in a complexity of combinations. A 5D QS can also re-estimate the developing design an endless number of times providing feedback on the estimate variances and corrective suggestions' (Mitchell 2012, p.4). The ability to simulate a range of design options with real-time cost advice sets the 5D QS apart and arguably places them at the top of the 'value chain' for project clients. This is simply not possible with the traditional 2D QS due to their labour intensive approaches – numerous 'what if' simulation cost calculations would take far too long manually. Mitchell (2012) refers to this as the 5D 'Living Cost Plan'. He argues that these modern techniques can be used within traditional frameworks but that it is the behaviour and how the technology is used that is more important than the software. He considers the following three areas to be the key for a successful 5D QS:

Wisdom - that has been developed through years of providing cost planning advice, observing construction and working with 2D and 3D design technologies, databases and knowledge sharing frameworks. **Intelligence** - this is collected and analysed via construction demand research, labour and material price research, as-built elemental building and civil cost analysis and functional performance measurement. **Technology Skills** - that interface in two directions with 3D models and enable calculation of accurate quantities and creation of dynamic links between model information, rate libraries and estimate templates. The dynamic links allow estimates to be calculated and recalculated easily and quickly every time the model information is revised and this is fundamental to Living Cost Planning (Mitchell 2012, p.5).

The Initial Concept Estimate Stage (LOD 100) involves the development of a fast initial concept estimate working with the model using programs such as Sketchup, Revit or an IFC format. The 5D QS uses their experience to factor in items that are not included in the model. Elemental cost benchmarking is established and a variety of alternative design solutions and analysis of functional performance carried out with the 5D QS providing real-time cost advice. The Schematic Design Stage (LOD 200) involves the 5D QS producing a schematic design estimate with dynamic links to model information thus forming the foundation for the 'living cost plan'. This provides the basis for providing updated estimates whenever information in the model is changed. Mitchell (2012) states that this can be used for 'forecast final cost, budget variances, value management, finance, funding, final investment decisions or in negotiations with a contractor' (Mitchell 2012, p. 6)

The Developed Design Stage (LOD 300) involves the 5D QS working with the developed design model in Revit or IFC format and providing extra levels of costing details with the cost plan broken down into sub-elemental and trade categories. The model information will typically need to be supplemented with 2D on screen measurement as required. Coding systems are used to classify and categorise the information. During the construction stage the contractor's rates and prices can be included in the model and then form the basis for variations, change orders and claims. The Cost Integrated Construction Model (LOD 400) emerges as the information in the model is revised for construction purposes culminating in the As-Built Cost Data and Facilities Management (LOD 500) stage. This requires validation and synchronisation between the as-built model and the Facility Management requirements with cost data refined and adapted by the 5D QS. Mitchell states that 'instead of spending

90% of the available QS time calculating quantities, an experienced 5D QS spends the majority of QS time applying wisdom and intelligence to generate savings and efficiencies. Once the model is established it is leveraged to calculate and recalculate costs extremely fast for different scenarios and alternative materials. 5D BIM provides the ability to drive costs for buildings, infrastructure, heavy engineering or land development in the direction that is wanted' (Mitchell 2012, p.9).

5.4. BIM Execution Plan (BEP) Cube

Mitchell Brandtman have developed a BIM Execution Plan (BEP) cube to illustrate the requirements for effective BIM implementation. It involves the Project Phase (Process), Collaboration (Behaviour) and Level of Development (Technology) and is shown in Figure 3.

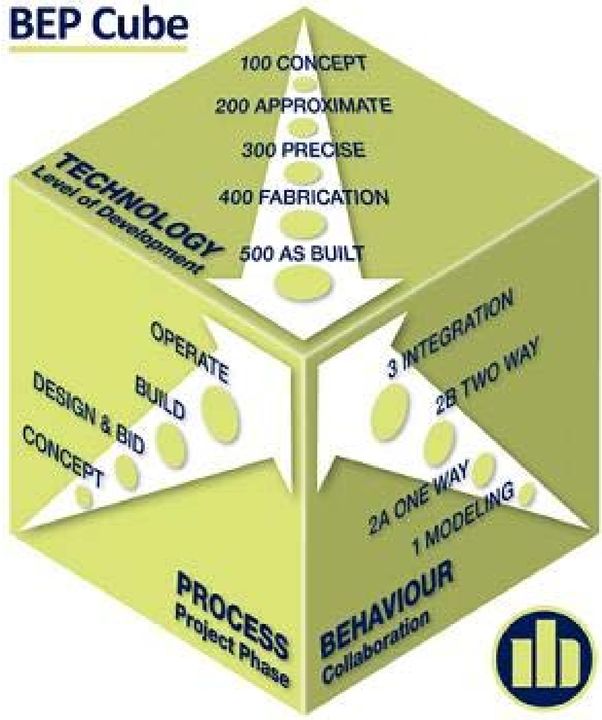

Figure 1 – BIM Execution Plan (Mitchell 2012, p. 3)

They provide the following explanation for the plan. 'When the desired project outcome is positioned on each of these scales the project team is more focused and achieves a high level of clarity about the important information to be included in the BIM. We have learnt that the best approach is to serve the right information, to the right people at the right time. When this isn't done the information can just become clutter. This is the issue at the core of the future development of BIM ie. one single integrated model versus a "federated model" comprising a collection of models. The three scales of process, behaviour and technology need to mature to better push and pull information effectively' (Mitchell Brandtman 2013, p.1)

5.5. Core Competencies

Whilst these innovative approaches are the hallmark of the firm, Mitchell contends that all of this is useless, and in many cases counterproductive, if staff do not have sufficient expertise in the core competencies of the QS profession. Developing competencies in construction knowledge, site experience, documentation understanding, measurement knowledge and other core quantity surveying knowledge areas are as important as they ever were.

6. CONCLUSION

The innovative approaches to BIM and automated quantities implementation by firms such as Mitchell Brandtman are perhaps too far ahead for many in the profession/industry who have yet to venture down this path in any meaningful form. For these firms, fundamental shifts in their business practices are required and this all takes time to develop. However, the competitive advantages already being realised by firms such as Mitchell Brandtman are likely to provide more of a catalyst for change in the profession than anything else. The longer firms delay their entry into the BIM and automated quantities world the further other firms with these capabilities will progress and add to their competitive advantage. The strategies taken by these firms to embrace these technological tools and adapt their business practices accordingly provide considerable inspiration and assistance for not only other quantity surveyor firms but for the profession generally in Australia.

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A NEW METHODOLOGY FOR DECIDING ON CONSTRUCTION PROJECT EARLY TERMINATION

Polyneikis Stroggylis
Aristotle University of Thessaloniki, Thessaloniki, Greece, polyneik@civil.auth.gr

Yiannis Xenidis
Aristotle University of Thessaloniki, Thessaloniki, Greece, ioxen@auth.gr

Abstract

Construction projects face a great number of challenges and obstacles that force for prompt evaluation of the achieved progress in delivering according to planning. In many cases the construction project manager has to decide whether the project is viable or early termination is a realistic option. Currently applied tools and approaches that facilitate this decision are mainly performance-based for an issue, though, which entails more parameters than performance. An extensive literature review reveals a significant shortage of a comprehensive, quantitative framework that is required for deciding early construction project termination. This paper aims to contribute in filling the identified gap in the literature by proposing such a framework. The research methodology involved a thorough review of literature and case studies concerning the critical factors that lead to construction project early termination and of the currently dominating approaches for project performance evaluation. The categorization of the critical factors according to the knowledge areas proposed by the Project Management Body of Knowledge standard allowed for the identification of specific limitations in quantifying those critical factors that are not associated with project performance. The proposed new methodology to overcome these limitations is based on an existing framework, which is significantly extended to include the most critical of the identified critical factors that lead to early termination. These critical factors are evaluated in various scenarios developed through scenario analysis and appropriate indicators, developed in the context of this research, are assessed. The quantitative values of the indicators constitute the inputs to an equation that assesses, on a scenario basis, the overall viability of the project under investigation. The final outcome of this equation is used for the decision on the project's continuance or early termination. The application of the methodology is presented in a demonstration example to provide the proof of the methodology's applicability.

Keywords: decision-making, methodology, performance, project cancellation, project early termination.

1. INTRODUCTION

Projects fail! Ojiako et al., (2007) report a failure rate of 30% in information technology projects that cost up to $145 bn/year. Safai et al., (2011) report that the major developer Dubai Land Department has cancelled 217 projects up to May, 31st 2011. The list of projects failures is endless, especially if one counts among them those that despite being failures were never terminated for several reasons. Such, historical, cases are the Suez Canal with a cost overrun up to 1900%, the Channel Tunnel with a cost overrun up to 80%, and the Ajaokuta Steel Complex in Nigeria that after a 20 years schedule overrun was still under construction (Flyvbjerg et al., 2005 and Flyvbjerg, 2007 in Ojiako et al., 2007).

A significant part of the literature has been devoted to the identification of the drivers and factors that lead to project failure focusing on the appropriate management to prevent project failures. Given that projects still (and will) fail in numerous cases, maybe it would be of more benefit to focus on other related issues, such as when would be the proper time to terminate a project or how one could determine whether it is better to finish or abandon a derailed project.

In order to answer to these questions in the context of this research, the following methodology steps were followed:

- Identification of the critical factors affecting construction projects performance (CPP). A detailed review on early terminated projects, worldwide, highlighted the most significant among those factors in project performance appraisal that should be linked to the project early termination decision. Furthermore, it was achieved to associate the most significant among the identified critical factors to the various project dimensions as defined by the Project Management Body of Knowledge (PMBOK) standard (PMI, 2008).
- Identification of CPP evaluation methods. A detailed review on the respective literature helped to identify the most valid current methods and practices that introduce performance metrics to assess the progress and sustainability of a construction project.
- Identification of existing methods on deciding a project's early termination. A detailed review on the respective literature revealed that such methods are either quantitative and extremely focused on particular projects' dimensions or mostly high-level and qualitative when including more parameters in the analysis. The existence of the second category should be anticipated considering the scarcity of data and the limited knowledge management in construction, which renders difficult any attempt to set up an analytical solution for this decision problem.
- Development of a new methodology to decide upon project early termination. The proposed methodology attempts a more quantitative approach on the determination of early termination of a construction project based on the collective findings of the previous steps and scenario analysis, which is considered as more appropriate for the research question compared to other tools or frameworks (e.g. statistical analysis).

The abovementioned steps as well as a demonstration example of the proposed methodology are presented in the following sections of this paper.

2. THE MOST CRITICAL FACTORS THAT LEAD CONSTRUCTION PROJECTS TO EARLY TERMINATION

The issue of performance of construction projects has been extensively studied so far. The best sources for such studies are actual projects that were either successful or complete failures. A comparison between cases from both categories reveals those factors of critical nature and their appropriateness to include in a project early termination decision method. In the context of this research, various projects cases were studied through the respective literature including the cancelled water supply projects in Nigeria (Sonuga et al., 2002) or the cancelled groundwater projects in Ghana (Frimpong et al., 2003).

The next step was the survey in the literature with regard to the Critical Success factors (CSF's) and the Key Performance Indicators (KPI's) in projects. The CSF's are those factors whose performance will critically affect the outcome of the project, while the KPI's are the metrics for the CSF's performance. Starting from the very extensive and thorough work that was made by Damianou (2010) on the review of CSF's/KPI's of construction projects, several other works were very important towards summarizing a vast literature on performance appraisal in construction projects (e.g. Cao & Hoffman, 2011; Li et al., 2011; Shtub et al., 2004, etc.). For example, Chan & Chan (2004) proposed a list of subjective and objective KPI's of construction projects, while Shenhar et al., (2001) claimed that there should be discrete success/failure criteria depending on the projects' type, identifying four types of projects: a) low tech projects, including construction projects, known product manufacturing, etc., b) medium tech projects, including industrial and product development projects, c) high tech projects, including software and warfare development projects, and d) super high tech products including space projects. For low tech projects wherein construction projects are met, the most critical factors according to Shenhar et al., (2001) are coming down to project efficiency, i.e. schedule and budget compliance. In contrast, for super high tech projects the most important success factors are innovation and cultivation of the chances for future domination.

The listing of CSP's/KPI's is both outside of the scope of this paper and impractical due to space limitations; however, the literature study allowed the identification of the most critical factors and their association to the various project dimensions as defined by the Project Management Body of Knowledge (PMBOK) standard (PMI, 2008). The decision on the most critical among CSF's was based on two criteria: a) frequency in the respective literature, and b) severity in project's development. Table 1 presents this classification. As shown there, there is normally one to three major factors per project dimension that are dominant among other CSF's in a project's progress appraisal. The identification of these factors served the aim to focus on them and propose a methodology to comprehensively consider them in a project early termination decision. As it can be seen in Table 1, not all knowledge areas are listed; this does not mean that there are no CSF's related to the procurement and communication management areas (those omitted from the table) but that early termination is not decided upon CSF's related to these areas.

PROJECT DIMENSION (KNOWLEDGE AREA)	**MOST CRITICAL FACTORS**
Schedule Management	• Over schedule
Cost Management	• Over budget
Scope Management	• Specification-Deliverables mismatch • Scope creep
Quality Management	• Quality upper/lower limits violations
Human Resources Management	• Staff shortage
Risk Management	• Exposure to intolerable hazards (political, social, legal, environmental) • Occupational accidents
Integration Management	• Competitive product that cancels the need for the project • Elimination of project need

Table 1. The most critical performance issue associated to a project's dimension based on PMBOK

The identification of the most critical factors leading to early construction project termination provided the set of variables to consider in the context of the proposed methodology for evaluating the potential of project cancellation; however, a prerequisite was the review of existing CPP appraisal methods, in order to identify their capacities and limitations and evaluate their efficiency in modeling the identified variables. The findings from the review of CPP appraisal methods are presented in the next section.

3. CPP APPRAISAL METHODS

In general, two distinct approaches exist on the projects early termination issue. The first focuses on the monitoring and measurement of the classical criteria in project performance, i.e. time, cost, and scope, both collectively (most often in pairs, e.g. cost/scope) and individually (e.g. budget performance, schedule performance). The second considers the problem as a multi-criteria one and, consequently, proposes tools and methods from the multi-criteria analysis domain to solve it. Table 2 summarizes those methodologies and techniques reviewed in the context of this research providing, also, references for further reading.

Methodology/Technique	Source
Checklists	Shtub et al., 2008
Tipping Point Failure Model	Taylor & Ford, 2006
Net Project Execution Cost and Net Product Operation Value	Yu et al., 2005
Project Termination Point System	Kapur, 2001
Project Termination Decision Support System	Schafer & Mantel, 1989
Early Termination Monitoring System	Meredith, 1988

Table 2. Project early termination methodologies and techniques

The methodologies presented in Table 2 vary in terms of simplicity, from easy to apply checklists to more complex and theoretical approaches such as the "tipping point failure" method of Taylor & Ford (2006). One of the most analytical and clear methods is that proposed by Schafer & Mantel (1989), who claim that every construction company should develop its own project early termination decision support system, based on: a) the historical data of former projects of the company, b) the real performance data of the current project, and c) the personal estimations of company's managers. Schafer & Mantel (1989) propose the application of the Delphi method, in order to determine the project performance criteria and their weights and then they assess a project score based on Equation (1).

$$Dit = \sum_j (wj\ Sijt) \prod_k Iikt \tag{1}$$

where D_{it} is the score for a project i in time period t, w_j is the weight of the criterion j, S_{ijt} is the score of project i for the criterion j in time period t, and I_{ikt} = 0 if the critical constraint k is violated in project i in time period t and I_{ikt} = 1, if not.

The approach of Schafer & Mantel (1989) provides a metric for evaluating a project's performance, which, however, once obtained is not used in a definite, but rather in a relative way. Schafer & Mantel (1989) propose that D_{it} score should be compared between subsequent periods in the project's execution duration and only if a critical (i.e. bigger than 25%) decline is recorded, a project should be considered for early termination taking into consideration other factors as well. In this way, a stepwise derail of the project in terms of performance could be falsely neglected provided that it would remain in the range of 0-25% compared to the previously recorded, also low, performance.

The following section introduces the methodology developed in the context of this research, which attempts to successfully overcome existing pitfalls in other approaches and provide an analytical and quantitative method for deciding on a project's early termination.

4. THE PROPOSED METHODOLOGY FOR DECIDING ON CONSTRUCTION PROJECT EARLY TERMINATION

The various CSF's for construction projects that have been identified from the literature review and their different impact on the project's performance and sustainability require an integrated management framework, in order to collectively treat all the factors measuring the project's performance. Such a framework was developed, in the context of this research, based on the previous work by Pinto & Mantel (1990).

Pinto & Mantel (1990) proposed a scheme of two broad groups for the factors affecting a project's development, namely project strategy and project tactics. They considered these groups spanning in the whole life cycle of a project's development, yet with various influence depending on the stage of development; project strategy factors are mainly significant in the project's early stages (conceptual and analytical planning), while project tactics factors are mainly significant in the project's late stages (project execution, control and finishing). The method proposed in this paper, broadens this concept and identifies four level of project factors significance, namely: a) project identity, which includes issues of project's scope and specifications, b) project strategy, which includes issues of management methods and adaptation to the external environment, 3) project tactics, which includes issues of costs and schedule performance, and 4) project engineering, which includes issues of productivity, application of construction methods, and technical risks. These four levels are visualized in Figure 1, in the form of a reverse pyramid, which denotes that the more appropriate the treatment of the critical factors included in a level, the less problems are anticipated in the lower level. Therefore the project's engineering level that contains all the issues directly related to the project's production at the project's execution stage, can be easily managed provided that appropriate measures have been taken at the previous level, i.e. that of the project's tactics.

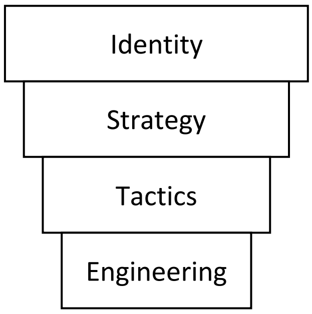

Figure 1. The four levels of significance for a project's performance

The next step was to associate the most critical of CSF's for construction projects to the four levels of a project's performance as defined in the context of this research. These associations for the thirty-five (35) CSF's that were selected were made based on the PMBOK knowledge areas, the project's life cycle phases (Conceptual planning – Analytical planning – Execution/Construction – Finishing/Delivering), and the significance of the CSF's to each phase of the project's life cycle based on literature findings. For each factor a set of "possible situations" (two to five depending on the factor) was defined based on the factor's nature and the context of construction projects. A full description of the associations and "possible situations" defined is given in Stroggylis (2012).

Once all factors have been described in the context of the proposed methodology, the impact of each distinct level to the overall project performance is calculated by the Equations 2-5.

$$S_{eng} = \frac{G_{1,1k}*S_{1,1k}+G_{2,1k}*S_{2,1k}+ \ldots\ldots G_{n,1k}*S_{n,1k}}{G_{1,1k}G_{2,1k+}+ \ldots\ldots G_{n,1k}} \quad (2)$$

$$S_{tact} = \frac{G_{1,2k}*S_{1,2k}+G_{2,2k}*S_{2,2k}+ \ldots\ldots G_{n,2k}*S_{n,2k}}{G_{1,2k}+G_{2,2k}+ \ldots\ldots G_{n,2k}} \quad (3)$$

$$S_{str} = \frac{G_{1,3k}*S_{1,3k}+G_{2,3k}*S_{2,3k}+ \ldots\ldots G_{n,3k}*S_{n,3k}}{G_{1,3k}+G_{2,3k}+ \ldots\ldots G_{n,3k}} \quad (4)$$

$$S_{id} = \frac{G_{1,4k}*S_{1,4k}+G_{2,4k}*S_{2,4k}+ \ldots\ldots G_{n,4k}*S_{n,4k}}{G_{1,4k}+G_{2,4k}+ \ldots\ldots G_{n,4k}} \quad (5)$$

where $S_{i,jk}$ is the score of the i^{th} factor, at level *j* (j=1 for the engineering level, j=2 for the tactics level and so on), in project's life cycle phase *k* (k=1 for the conceptual planning phase, k=2 for the analytical planning phase and so on), while $G_{i,jk}$ is the weight factor of the i^{th} factor, at level *j*, in project's life cycle phase *k*. In equations 2-5, the $S_{i,jk}$ scores are calculated depending on appropriate assessment formulas that describe each factor *i*, while the $G_{i,jk}$ weights are determined by the analyst with the use of an appropriate method (e.g. the Analytic Hierarchy Process-AHP).

The next step is to calculate the overall project's performance score by using Equation 6.

$$S_{tot} = \frac{1*S_{eng}+2*S_{tact}+3*S_{str}+4*S_{id}}{10} \quad (6)$$

In Equation 6, S_{tech}, S_{tact}, S_{str}, and S_{id} are the scores of each project's level respectively. The coefficients of the project's levels scores in Equation 6 have been defined to ensure consistency in the calculation of the overall performance based on the levels' performances. More specifically, a threshold has been assumed for the maximum value of a level's score, which once it is reached or exceeded, it signifies the project's need for termination. This score is the value of hundred, i.e. $\max S_{tech} = \max S_{tact} = \max S_{str} = \max S_{id} = 100$. Therefore, in the hypothetical case where all project's levels score their maximum values, the overall project's performance should reach the threshold's value; this is achieved by the appropriate coefficients in Equation 6. The coefficients values, also, allow the consideration of the different significance of the four levels in the project's early termination decision; the analogy is inspired by the Pythagoras' tetractys, which resembles the reverse pyramid illustrated in Figure 1.

Having available all the equations, it is possible to investigate the marginal scenarios for all the critical factors in each project's life cycle phase under various "possible conditions". This is a backwards process, where the scenario is defined in terms of the project's levels scores and through the equations (2)–(6), the marginal values of the critical factors are assessed for all "possible situations". The final outcome is the calculation of specific values for each factor that are used in the forward processing of equations (2)–(6) towards the calculation of a score that should indicate the potential need for early project termination under the assumption of a specific "possible situation". The marginal values for all critical factors associated to the four project levels for every "possible situation" in all project's life cycle phases are summarized in tables that are available to the analysts and can be updated based on their cumulative knowledge and experience after the development of several projects. Such tables are not presented in this paper due to space limitations, but they can be found in Stroggylis (2012).

A demonstration example of the proposed methodology is presented in the following section.

5. A DEMONSTRATION EXAMPLE OF THE PROPOSED METHODOLOGY

Suppose that an inexperienced contractor of a road project, currently at the execution phase, experiences the following issues:

- The lower limits of the Los Angeles test for the aggregates have been violated four times in the last month. The site-engineers claim that this could be risky for the road's final surface, but would be relatively easy to resolve by replacing those aggregates with harsher and flint ones.
- Two excavators are facing severe damage and they are, already, out of use for two weeks. The equipment supplier cannot be reached and there is no one that could fix them.

This is a situation that can be modeled and resolved by the proposed methodology, in order to decide whether the project faces an early termination option or not. Based on the situation's description and the tables with the marginal values for all critical factors, the scores of these factors are calculated. Table 3 presents the marginal values for all critical factors associated to the level of engineering.

No.	CSF	Possible Situation	Score
1	Technical specifications meeting	Complete meeting of technical specifications	-30
		Relative meeting of technical specifications	0
		Small disagreements on technical specifications meeting	30
		Complete mismatch of technical specifications	90
2	Work productivity	Productivity greater than the planned	-15
		Productivity equal to the planned	0
		Relatively low productivity	24
		Very low productivity/ zero productivity	51
3	Technical complexity of the project	Simple and well known project	-24
		Usual project, medium complexity, low uncertainty	0
		Innovative project with great complexity	24
		Extremely complex project with great levels of uncertainty	72

No.	CSF	Possible Situation	Score
4	Technical support	Full support by technicians and suppliers	-30
		Usual support by technicians and suppliers	0
		Insufficient support by technicians and suppliers	30
5	Frequency of medium quality thresholds violations	Absence of violations	0
		Few violations in big time periods	15
		Continuing violations	45
6	Severity of upper/lower quality threshold violations	Absence of violations	0
		Violations with fixable consequences	45
		Violations with non-fixable situations	120
7	Contractor expertise	Great experience of contractor for the project	-60
		Satisfying experience of contractor with challenges for the project	0
		Small or zero experience of contractor for the project	60
8	Appropriateness of design	Confirmation of the project construction design	-30
		Construction design that need changes	45
		Wrong construction solution for the project	90

Table 3. The marginal values for all critical factors at the level of engineering

Four CSF's included in Table 3, i.e. 3, 4, 6, and 7 can model the situation described in the case study. The $S_{i,jk}$ scores for the four factors identified at the engineering level (j=1), at the project execution phase (k=3), obtain the following values:

- $S_{3,13}$ =-24, because the project can be considered as a simple and well known one in terms of technical complexity.
- $S_{4,13}$ =30, because the technical support can be considered as highly insufficient.
- $S_{6,13}$ =45, because the violations of the quality thresholds for the aggregates have fixable consequences.
- $S_{7,13}$ =60, because of the contractor's inexperience.

With the use of the appropriately pre-determined $G_{i,jk}$ weights and Equation (2) the score at the engineering level obtains the value, S_{eng} =35.18 (for $G_{3,13}$ = 2, $G_{4,13}$ = 3, $G_{6,13}$ = 3, $G_{7,13}$ = 3). Since, in this demonstration example, there are no other factors to model involving any other level, with the use of Equation 6 the overall project's performance score is S_{tot} =3.518 (for S_{tact} = S_{str} = S_{id} =0), a value that indicates that there is practically no reason to consider an early termination for the project.

6. CONCLUSIONS

Decisions on early termination of construction projects are difficult, especially if the projects are at an advanced stage of development. However, it is imperative for the stakeholders of these projects to identify a situation that accumulates losses and end it timely with the less possible harm. A great number of critical factors have been suggested in the past, as indicators of project's performance; therefore appropriate monitoring of these factors could support an early termination decision. Beyond this indirect method, some methodologies and techniques exist to directly provide a response to the question of project early termination, which in most of the cases are qualitative in nature or partial in terms of the considered parameters.

This paper proposes a new semi-quantitative methodology that integrates various sets of the most critical of CSF's, in a framework that supports the decision on early project termination through an appropriate structure of mathematical equations built in the context of this research. Four levels, namely the engineering, the tactics, the strategy, and the identity level are identified and associated with the critical CSF's; these levels are investigated under the specific conditions met at a specific project's life cycle phase where the early termination option is examined. This investigation is further facilitated through weightings of the critical CSF's, which are appropriately pre-determined by the methodology's user.

Several issues require further improvement concerning the proposed methodology, such as the more systematic determination of the weights of the levels scores and the methodology for determining the CSF's marginal values; the use of fuzzy logic is investigated for both issues. It is considered, however, that the proposed methodology, at this stage, may constitute a new approach for timely and effective decision-making on construction projects early termination in a comprehensive, quantitative, adaptable, and easy to apply manner.

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USE OF PRESTRESSED TRANSFER GIRDER TO UNDERPIN AN LRT PIER

Teng Hooi Tan
School of Science and Technology, SIM University, Singapore, thtan@unisim.edu.sg

Kok Hua Ang, Chee Cheong Chiang, Li Ching Sheng
Land Transport Authority, Singapore

Hee Kung Chua
Lum Chang Building Contractors Pte Ltd, Singapore

Abstract

The alignment of a new of a MRT line runs directly under an LRT pier which is in operation. The construction of the tunnel is by the cut-and-cover method and the steel-pile foundation for the pier has to be removed. Owing to space constraint and difficult ground condition, the conventional method of using new replacement piles for the pier not only poses construction difficulties, the risk of excessive pier movement on the LRT operation is high. A post-tensioned transfer beam spanning across the excavation provides an effective solution to the problem. It has the added advantage of providing the option of “load balancing” to control the pier movement and also an unobstructed space beneath the pier during the tunnel construction. When the permanent support for the pier is eventually provided by the new tunnel structure, the transfer beam is no longer needed. Instrumentations are installed to monitor the movements and to also facilitate the load balancing process. This unconventional method not only reduces risks, it also saves considerable construction time and cost.

Keywords: Cut-and-cover, Excavation, underpin, prestressing, transfer beam.

1. INTRODUCTION

Contract 912 is one of the Design and Built (D&B) Contracts for the construction of Downtown Line 2. It consists of one Civil Defence MRT station at Bukit Panjang (BKP) and 1.6km of cut-and-cover tunnel.

The Bukit Panjang LRT is a light rapid transit system in operation that provides connection between the Bukit Panjang estate and the Choa Chu Kang MRT Station. The entire LRT viaduct system is supported by reinforced concrete piers. At one point, the tunnel alignment runs directly below the foundation system of one of the piers, P521 (see Figure 1). The foundation system of P521 comprises 10 numbers of 350x350x131kg/m steel H-piles driven to

9.9m below the soffit of its reinforced concrete pile cap. The toes of these steel piles are above the proposed tunnel structures.

The construction of the new tunnel structures by cut-and-cover method will adversely affect the structural integrity of P521 and performance of the existing LRT system. As a result, there is a need to underpin the pier. This paper describes the development and design of the underpinning scheme and the challenges and constraints encountered during the construction.

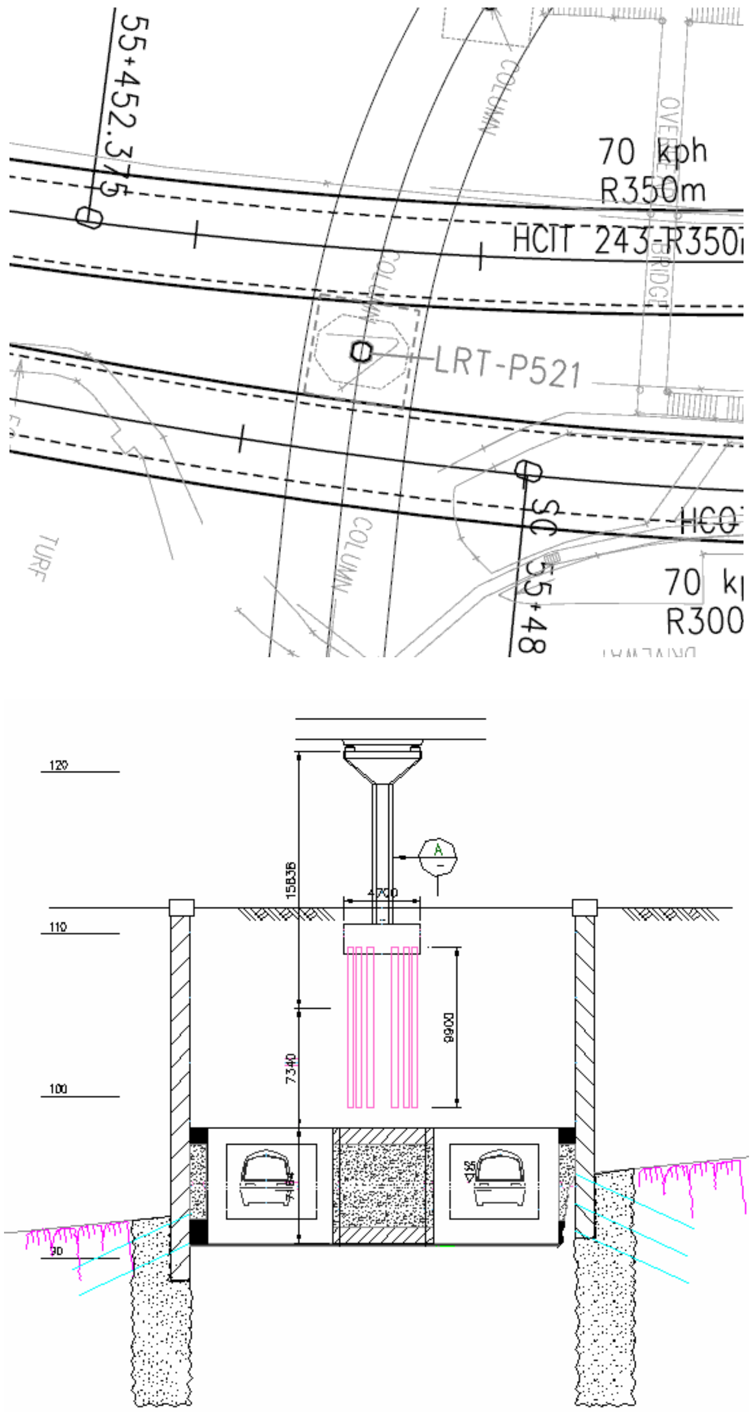

Figure 1. Plan and Sectional View of LRT Pier and the MRT tunnels

2. THE REQUIRMENT AND CONSTRAINTS OF THE UNDERPINING

2.1. The geology and the foundation of Pier 521

The geology of the site consists of 3m of Fill at the top level, followed by a layer of about 3m to 5m of Kallang formation of mainly Fluvial Sand (F1) and Fluvial Clay (F2), underlying it is the Bukit Timah Granite formation (GVI to GI) of varying weathering grade.

2.2. Design development

The original scheme during the tender called for a conventional underpinning scheme using bored piles to be socketed into GIII/GII rock for 2m below the formation level of the cut-and-cover tunnel. A new pile cap of size is to be constructed underneath the existing pile cap with a construction gap of approximately 400mm where jacking and shimming is to be carried out to transfer the pier loadings to the new pile cap. Once the transfer of loadings is completed, the gap between two pile caps is to be permanently grouted and the original steel H-piles are then to be cut. Different pile sizes and spacings were considered to fit into the space constraint and to minimize the influence. Details of the schemes are described elsewhere (Tan TH et al 2010). The underpinning system is to be designed for a minimum working load of 20,500kN. To comply with the allowable movements as stated in the Code of Practice for Railway Protection 2004, the total viaduct settlement shall not exceed 10mm and the differential settlement not exceeding 10mm or 1:500 whichever lesser. In addition, the vibration limit shall not exceed 15mm/sec peak particle velocity.

The exploratory boreholes revealed that rock head expected at that location is several metres above the tunnel formation level. Hence, the conventional underpinning scheme was found to be difficult and risky owing to the following reasons:

– Difficulty in installing the bored piles in rock due to the limited machine capacity

– Effect of the new bored pile construction on the existing steel piles

– Effect of rock excavation on the new bored piles

The details of the difficulties and risks are described elsewhere (Tan TH et al 2010). The risks can be mitigated by using post-tensioned (PT) transfer beam as an underpinning method for the existing LRT pier.

3. POST-TENSIONED TRANSFER BEAM SYSTEM

An alternative approach of underpinning scheme is by using post-tensioned transfer beam system. “Load Balancing” concept (T.Y.Lin & Ned H. Burn, 1982) was used to determine the structural system and prestressing requirement. This scheme can better mitigate the construction challenges and its associated risks including the residual effects to the existing steel H-piles. In addition, it provides a clearer load path and permits adjustment of prestress to balance the support load in maintaining the desired performance.

3.1. Structural System

The transfer beam is designed as a simply supported post-tensioned beam that supports the existing LRT pier P521 during construction stage. Part of the existing P521 pile cap and its steel H-pile will be integrated with the PT transfer beam in order for the system to function as a whole. It is approximately 24m long (L), 7m wide (W) and 2.5m deep (D). Its dimensions and level are determined by taking into consideration of the existing P521 pile cap dimensions of 4.7m (L) x 6.4m (W) x 1.8m (D), cross section width of the excavation and top 2m of free encumbrance. Cellular air voids are incorporated in the transfer beam to reduce its self weight.

Temporary diaphragm walls are adopted as supports for the PT transfer beam. It also acts as earth retaining stabilising structures during excavation.

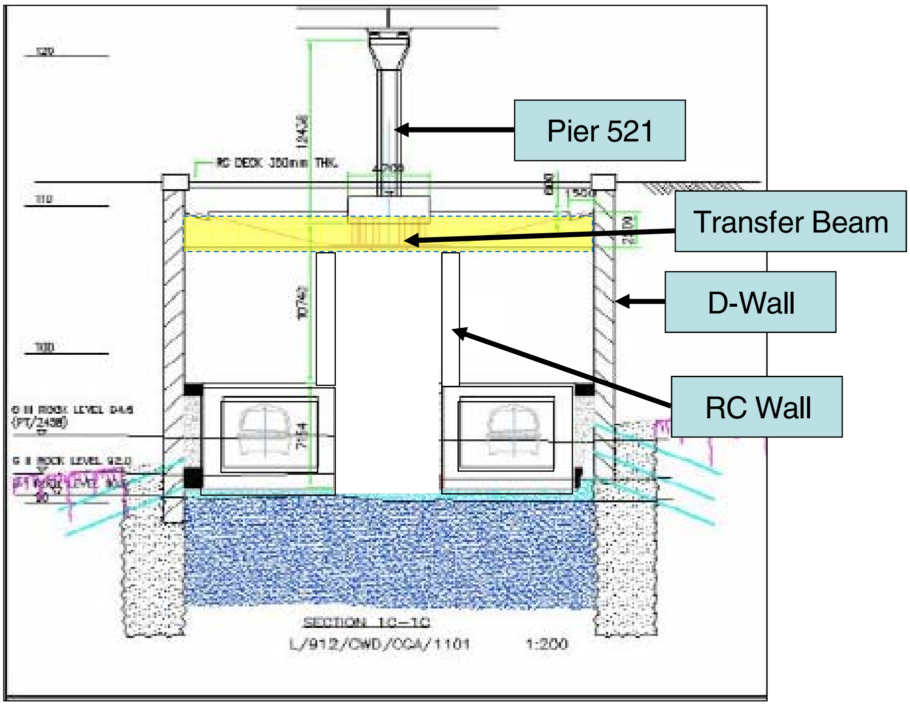

Figure 2 Cross-sectional view of the underpinning scheme

Upon completion of permanent tunnel structures, two new reinforced concrete walls (7m wide x 1m thick) are to be constructed from the tunnel structures to underside of the simply supported PT transfer beam and converting the single-span structure into a three-span structure. This facilitates end spans of the transfer beam to be removed and hence the completion of underpinning works for P521 under permanent stage. Figure 2 shows the cross sectional view of the underpinning scheme.

3.2.Analysis and Design

The transfer beam is checked at all stages for service and ultimate conditions. It is also checked for transfer stages to ensure the safety during construction. In the analysis, Finite Element Model (FEM) is set up to simulate the behaviour of the transfer beam under various load conditions and load combinations for both temporary and permanent stages. The model includes time dependent effects to account for lateral load due to excavation, effects of creep and shrinkage and elastic shortening. In the design, the vertical deflection of the transfer beam is predicted to be 1.3mm upwards upon full load transfer from the piles (after cutting). To ensure a gradual transfer of forces from the piles to the beam, the stressing of the tendon and associated cutting of piles were carried out in 3 stages.

PLAXIS is employed to analyze the diaphragm walls which act as earth retaining structures and also as supports for the PT transfer beam at temporary stage. Stages of construction reflecting the sequence of temporary strutting works, variable soil types, toe socket depth are considered in the model. The geotechnical design parameters used are to comply with minimum values given in the LTA's Geotechnical Interpretation Baseline Report. In addition, sensitivity study from possible effects such as unplanned excavation, drained/undrained conditions, level of water table, one strut failure, level of struts, etc are included to mitigate unexpected risks. From the analysis, most critical behaviours of diaphragm walls are predicted and worst forces induced are obtained for design.

The reinforced concrete walls as the new permanent supports for the underpinning system will be resting on the tunnel structure under permanent stage.

3.3. Advantages of the PT scheme

Post-tensioned transfer beam is commonly used in building structures to create large space of column free areas such as auditorium, transition from commercial floor to residential floor, environment deck in condominium with basement car park, etc. Similar concept is used in the P521 underpinning works to create an obstruction freed space for the construction of tunnel structures. It is therefore a proven and common construction technique.

The option of load balance adjustment in the PT transfer beam offers the greatest advantage to allow the pier movement to be controlled to the acceptable limit. By integrating with the existing pile cap coupled with the nature of shallow depth of PT transfer beam means shorter length of the existing steel H-pile will be exposed when performing the underpinning works.

The lateral disturbance to the existing steel H-pile is eliminated as there is no new foundation piles need to be installed at the vicinity. Hence the impact to structural integrity and capacity of the existing steel H-pile is minimised.

The system also offers less risk, less obstruction and a more robust strutting system for excavation and construction. The difficulty in casting the new pile cap is now become less complicated and the load transfer is much clearer. Rigid supports provided by the two new reinforced concrete walls are resulting in greater long term safety.

4. THE CONSTRUCTION AND THE LOAD TRANSFER

4.1. Instrumentation

Real time monitoring (movements and vibration level) of pier P521 was continually carried out to monitor and ensure the stipulated limits are not exceeded.

4.2. Risk Managment

Risk management is an approach adopted in all rapid transit system projects to control the risks associated to design and construction works to an acceptable level. The hazards identified for the underpinning of LRT P521 are as follows:

a) Excessive movement or collapse of the existing LRT pier due to incorrect design model, uncertainties in geotechnical design parameters, incorrect work sequence, inadequacy in retaining system, and excessive ingress of ground water during construction.

b) Undesirable pier movement may also occur due to wrong stressing sequence applied to PT transfer beam, under or over stressed of post-tension tendons and incorrect loading assumption.

c) Undesirable vibration to LRT structures and operating system due to uncontrolled or inappropriate method of demolition and sequence of works.

d) Bursting of ungrouted tendon strands due to demolition works.

e) Unforeseen ground conditions due to insufficient soil investigation data.

The impacts of the hazards are assessed and mitigation measures are provided.

4.3. Unforeseen problems encountered

There were several unforeseen problems that required modification of the transfer beam during the construction e.g.

a) During the construction of the diaphragm walls, the pier moved towards the east by 5 mm. To avoid any further movement, bearing in mind the movement limit of 10 mm, especially at the excavation stage, a controlled excavation plan and a restraint system was developed to manage the difficulty.

b) Instead of 10 steel H-piles as shown in the as-built drawings, it was discovered during excavation that there were actually 12 piles, driven significantly out of place and slanted. Owing to extra piles and deviated pile positions, the stressing and pile cutting sequence has to be reworked. In addition, the space between the piles to accommodate the prestressing ducts and reinforcement was significantly reduced necessitating the redesign of the steel reinforcement installation and tendon stressing. Even then, a part of the PT beam next to the north face of pilecap had to be widened in order to cope with the shortfall.

c) Box-outs in the diaphragm walls were not constructed well resulting in extensive hacking to accommodate the critical reinforcement details at the connection between the wall and the transfer beam.

d) There were other obstructions caused by existing water pipe and adjacent micro piles that added constraints to the already difficult construction.

4.4. Performance of the scheme

The performance of the underpinning using the transfer girder was as predicted. The actual vertical deflection after full load transfer was 1.0mm upwards (versus predicted 1.3mm) and no cracking in the concrete was observed.

5. CONCLUSIONS

Underpinning of existing LRT structures using post-tensioned transfer beam is a practical and appropriate approach. It complies with the stringent requirements of the Code of Practice for Railway Protection and provides a safer construction method as obstructions and risks associated to construction activities are either mitigated or reduced to acceptable level. The load path in the system is clear and this allows the design and construction to be carried out confidently.

6. ACKNOWLEDGMENTS

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A REVIEW OF RESEARCH TRENDS INSOCIAL NETWORK ANALYSIS

Pelin Ipek Timurcan
İzmir Institute of Technology, Izmir, Turkey, pelintimurcan@iyte.edu.tr

Sevgi Zeynep Doğan
Izmir Institute of Technology, Izmir, Turkey, sevgidogan@iyte.edu.tr

Abstract

Significant literature has been dedicated to research studies on social networks (SN) and related issues over the past two decades. Both theoretical contribution and practical applications of social network analysis (SNA) in construction have been reported. This paper aims to explore and summarize the research trends of SNA related studies in three leading construction management journals SNA related journal articles published from 1998 to 2013 were analyzed in terms of their research focus, unit of analysis, and network metrics and measures. The framework of the theoretical contribution and the units of analysis via the employed SNA software were reported. The findings imply that SNA is a promising tool for the construction industry. Thus, advances in SNA studies were reviewed from conference papers available via technology-related databases. Research topics published in studied papers tend to focus on SNA automation; team formation and performance evaluation using SNA. Their adoption potential in the construction industry is investigated.

Keywords: social networks, construction management

1. INTRODUCTION

Since its emergence from sociology in 1930s (Moreno 1934), SN have been gaining wide attention from theoretical exploration to practical application. However, the research topics explored by the SNA method in the construction domain are diverse and demand an analysis of the SNA related issues. An analytical review of the reported literature within the SN domain may lead the way for future researchers to gain an understanding of the topic and to conduct associated research more thoroughly and efficiently. Retrieval from academic journals can be regarded as the most effective approach for particularly new researchers, to gain an in-depth insight into the research trends about a specific topic. Tsai and Wen (2005) stated that a systematic analysis of papers published in academic journals would help researchers explore the current status and future trend of a chosen topic. However, in the field of construction, no such critical analysis of SNA research has been undertaken to date. Therefore, this paper attempts to comprehensively review the SNA related literature in the three leading journals on construction management and to investigate the research trend of SN related studies. The first paper on SN was published in construction journals in 1998. Therefore SNA literature review is conducted from 1998 to 2013, inclusive.

2. CURRENT STATUS OF RESEARCH ON SNA IN CONSTRUCTION MANAGEMENT

SNA is a body of theory and methodology for the analysis of systems as networks of relationships. It is defined as a broad strategy for investigating social structure rather than formal theory (Otte and Rousseau, 2002).

The application of SNA is relatively new in the construction industry. Nevertheless, the volume of SN research in construction management has increased radically in recent years, as it has in many disciplines. In this paper, we first review and analyze the emerging SN paradigm in construction research. We begin with a conventional review of recent SN research published in recognized construction management related journals, namely *Journal of Construction Engineering and Management, ASCE (JCEM); Construction Management and Economics (CME); and Engineering, Construction and Architectural Management (ECAM).* (Search code was ''social network analysis'' in the title, abstract or keywords.)

Next, we analyze this research, developing a set of dimensions along with network studies conducted, including theoretical contribution, units of analysis and adopted software. 14 papers in relation to SN studies published in above mentioned journals between 1998 and 2013 are presented in Table 1.

AUTHORS and *YEAR*	**ARTICLE in *JOURNAL***	**THEORETICAL CONTRIBUTION**	**UNITS of ANALYSIS**	**ANALYSIS via *SOFTWARE NETWORK METRICS***
Loosemore, M. *1998*	Social network analysis: using a quantitative tool within an interpretative context to explore the management of construction crisis *in ECAM*	Provides an universal model for construction crisis by association of quantitative and qualitative methods.	The interactions between actors in a leisure center project during a construction crisis.	Degree centrality, closeness centrality, betweenness centrality, *via UCINET*
Thorpe, T. Mead, S. *2001*	Project-specific web sites (PWS): friend of foe? *in JCEM*	Provides a theoretical background on PWS, and describes SNA used to understand how PWS affects information push and pull	Three construction projects using project-based internet systems	Centrality, via Krackplot tool *via UCINET*

Pryke, S. *2004*	Analysing construction project coalitions: exploring the application of social network analysis *in CME*	Provides an exploration of the aplication of SNA as a new quantitative approach is construction industry	Aplication to the analysis of UK construction procurement	Point centrality degree centrality, closeness centrality
Pryke, S. *2005*	Towards a social network theory of project governance *in CME*	Provides an exploration of a very specific framework for the examination of the governance of construction coalitions using SNA	Information exchange networks of 4 UK construction projects	Network density, actor point centrality, *via UCINET 6*
Hossain, L. *2009*	Communications and coordination in construction projects *in CME*	Provides an exploration of the association between network centrality and coordination for a construction project.	Networks, centrality of actors and coordination scores	Network centrality *via UCINET 6*
Chinowsky, P., Diekmann, J., O'Brien, J. *2010*	Project Organizations as Social Networks *in JCEM*	Provides a SN model of construction introducing a dual-focus approach for enhancing trust and strong communication	Networks consist of actors from 4 engineering companies engaged in both management of design and construction	Network density, centrality, betweenness and power *via UCINET*
El-Sheikh, A., Pryke, S. *2010*	Network gaps and project success *in CME*	Provides a combined application of gap analysis and SNA to help practitioners exceed client expectations	Two construction projects in the academy programme of the DfES	Network density, centrality betweenness and power *via UCINET 6*
Park, H., Seung H.H., Rojas, E.M., JeongWook, S., Jung, W. *2011*	Social Network Analysis of Collaborative Ventures for Overseas Construction Projects *in JCEM*	Provides collaboration strategies considering relevant network patterns and their different levels of performance in the different networks	389 cases of overseas construction projects executed by Korean firms that involved collaboration from 1990 to 2006.	Density, direct/indirect ties, indegree/outdegree betweenness and closeness centrality triad *via Pajek* *via NetDraw*
Larsen, G.D. *2011*	Understanding the early stages of the innovation diffusion process: awareness, influence and communication networks *in CME*	Provides the use of SNA to map the communication networks in order to understand how actors become aware of an innovation	Pilot study: Members of CIOB, RIBA and RICS Case study: A division of a natural civil engineering firm	Direction, *via UCINET 6*

Ruan, X., Ochieng, E.G, Price, A.D.F., Egbu, C.O. *2012*	Knowledge integration process in construction project a social network analysis approach to compare competitive and collaborative working *in CME*	Provides a network perspective to analyze the knowledge integration for understanding the affects of collaborative working on overall project performance	A comparison of knowledge supporting networks from two different procurement systems: overall partnering and project partnering	Network centralization, network density, normalized degree centrality, *via UCINET*
Alsamadani, R. Hallowell, M. Javernick-Will, A.N. 2012	Measuring and modeling safety communication in small work crews in the US using social network analysis *in CME*	Provides an exploration of SNA as a tool to measure and model safety communication patterns and determine effective and ineffective safety networks	Nine construction firms in the Denver Metropolitan region of the US	Density, centrality, betweenness, *via UCINET* *via NetDraw*
Wambeke, B.W. Liu,M. Hsiang, S. M. 2012	Using Pajek and centrality analysis to identify a social network of construction trades *in JCEM*	Provides a SNA application as a method of identifying organizational SN of trades and analyzing the network to identify the key trades of a construction project	A data center construction project involving a general contractor and 43 trades	Degree centrality, Eigenvector centrality, *via Pajek*
Comu, S. Iorio, J., Taylor, J.E., Dossick, C.S. 2013	Quantifying the impact of facilitation on transactive memory system formation in global virtual project networks *in JCEM*	Provides a SNA application for measuring the impact of facilitators on performance of global virtual project networks engaged in the task work	Two facilitated and two nonfacilitated global virtual project networks	*Dyadic task relation,* *Subgroup formation,* *via UCINET* *via Statnet*
Solis, F. Sinfield, J. V. Abraham, D. M. *2013*	Hybrid approach to the study of inter-organization high performance teams *in JCEM*	Provides a hybrid approach that proposes the use of SNA as a complementary methodology to understand the interorganizational teamwork of construction projects	A cardiovascular center project in the state of California	Density, centrality, structural equivalence *via Pajek*

Table 1: SNA in Construction Management Research

3. FUTURE TREND OF RESEARCH ON SNA IN CONSTRUCTION MANAGEMENT

In order to gain an insight into the research trend on SN, this paper conducted a review of the related research published in technology-related conferences in addition to construction-related journals. The literature on SN is by now quite extensive. This paper examined recent research streams by conducting a two-stage review of the SNA, firstly by using 'IEEE.org' and 'dl.acm.org' databases and then a visual examination of all related papers, in the 9 selected conferences, CSCW, IsoLA2010 , ICDMW, HICSS'04, CTS, CSCWD, HICSS'07, RE, *CTIT*. Three categories in SNA advances, which are promising for construction research, are classified to include (1) SNA automation, (2) team formation, and (3) performance evaluation.

3.1. SNA automation

The advanced computing technology has facilitated automating the SNA process and tools. Researchers develop software that supports specific functions inspired from the SN methodology for a particular set of actors. Table 2 summarizes relevant research on SN in software development.

AUTHORS ***and YEAR***	**PAPER *in CONFERENCE***	**THEORETICAL CONTRIBUTION**	**UNITS of ANALYSIS**	**ANALYSIS *via SOFTWARE NETWORK METRICS***
Van Der Aalst, W.M.P., Reijers, H. A. Song, M. *2005*	Discovering Social Networks (SN) from Event Logs *in CSCW, ACM*	Provides a tool for mining SN using event logs of an actor initiating or completing an activity by combining workflow management and SNA	Event logs of a Dutch national public works department	Centrality, Betweenness, in-closeness, out-closeness, power, *via MiSoN* *via AGNA* *via NetMiner* *via UCINET*
Magdaleno, A.M., Werner,C.M.L., de Araujo R.M., *2010*	Analyzing Collaboration in Software Development Processes through Social Networks in *ISoLA2010, ACM*	Provides identification of the requirements to explore collaboration through SN in software development processes	Team members of a software development project called CDSOFT	Network density *via EvolTrack*
Koochakzadeh, N., Sarraf, A., Kianmehr, K., Rokne, J., Alhajj, R., *2011*	NetDriller: A Powerful Social Network Analysis Tool, ICDMW, IEEE	Proposes a new SNA tool called NetDriller which supports data analysis by facilitating fuzzy search on network metrics	Network construction fuzzy search on network metrics	Network Construction, Fuzzy Search on Network Metrics, *via NetDriller*

Table 2: SNA Augmented Software Products

Construction related SNA research utilizes UCINET, Pajek, NetMiner software, which solely use basic SNA tools. However, the recent motivation of SNA research is to construct and analyze SN that involves actors from a specific application domain. This trend is promising for the 'virtual construction project team' that is taking place in the A/E/C industry lately (Sher, Sherratt et al. 2012)

With the adoption of BIM, a network of interdependent architects, engineers, and other construction actors can collaborate to develop a virtual building information model of the planned structure (Taylor and Bernstein 2009). Proper mechanism is needed to explicit and measures the existing collaboration among participants in a construction project. SNA augmented BIM can be a candidate to reveal the creation process of virtual collaborations in the project network. SNA augmented BIM can support and enhance real-time sharing (Table 3).

BIM	**SNA**	**SNA augmented BIM**
Online Message	Relation Analysis	Identification of collaboration patterns
File Sharing	Visualization	Performance Evaluation
Project Log	Groups and Subgroups identification	Team Formation
Email	Relation Analysis	Optimal level of virtuality
Task Assignment	Role Definition	Measurement of e-contact

Table 3: SNA Augmented BIM

3.2. Team formation

SNA application on team formation is an emerging area of interest across many disciplines. Researchers create new teams by analyzing the existing ones to predict future collaborations. Table 4 summarizes relevant research utilizing SNA for potential team formation.

AUTHORS ***and YEAR***	**PAPER *in CONFERENCE***	**THEORETICAL CONTRIBUTION**	**UNITS of ANALYSIS**	**ANALYSIS *via SOFTWARE NETWORK METRICS***
Fu-ren, L., Chun-Hung,C., *2004*	Developing and Evaluating the Social Network Analysis System for Virtual Teams in Cyber Communities *in HICSS'04, ACM*	Provides a SNA system that draws graphs to present ego-centered SN or a team's whole SN and computes the values of attributes to facilitate teams' collaboration	Social network structures from virtual teams formed in a teachers' professional cyber community, called SCTNet	In-degree, out-degree, reachability rate, centrality, transitive rate, density, size *via WebDot*

Cheatham, M., Cleereman, K., *2006*	Application of Social Network Analysis to Collaborative Team Formation *in CTS, IEEE*	Provides a concept map in conjunction with SNA to identify colleagues and insure that the employees who are working on similar subjects are aware of one another	Co-authorship on published works, the author-specified keywords	Relation between two nodes
Monclar, R. S., Oliveira, J., de Faria, F.F., Ventura, L., de Souza, J.M., Campos, M.L.M., *2011*	Using Social Networks Analysis for Collaboration and Team Formation Identification *in CSCWD, IEEE*	Provides a mechanism to stimulate collaboration between the universities and research institutions and visualization of SN in the domain of cancer research	Social network of researchers at the Instituto Nacional de Ciência e Tecnologia (INCT) in cancer control	In-degree, out-degree network centralization betweenness centrality, social action, *via OLAP tools*

Table 4: SNA Studies in Team Formation

Current SNA related construction research allows us to see which project participants are already collaborating; how often the participants are working together; and how many others in the project team a given participant can reach through intermediary participants (Wambeke, Liu et al. 2012; Hossain 2009). Building projects are sets of links that organize professionals, teams, and firms in a connected way around a common purpose. During the implementation of a project, several problems related to the project network may arise, such as very isolated participants or peripheral members of a network may occur; or groups that fully concentrate on relationships may arise; or firms who are the only link between two distinct groups may appear; or the accumulation of team members in isolated points may take place (Monclar, Oliveira et al. 2011). Those inconveniences result in a series of communication and coordination problems, which ultimately cause knowledge losses to the project (Hossain 2009). Thus, it is vital for project success to conduct a series of collaboration analysis via SNA, by which we can monitor current collaboration success; and then assist in the formation of new teams. The participants who would work well in a group setting can be preferred or a successful specialist from a previous project network can be included in the new project team. SNA offers insight in assigning the roles and tasks to team members depending on the type and level of participation in the team (Cheatham and Cleereman 2006).

The construction industry is based on temporary networks where project participants are regrouped on almost every project with little regard to past network connections. The use of SNA metrics can provide valuable information about the informal structure of the organization to understand and verify how collaboration occurs in a multi-disciplinary, multi-team project, which is vital when creating new teams (Cheatham and Cleereman 2006; Monclar, Oliveira et al. 2011).

3.3. Performance evaluation

Traditional performance measurement techniques are inadequate when the examined team represents a complex and dynamic environment like virtual collaboration or BIM setting (Priscilla 2007). SNA has been used for measuring the performance of project teams in many other disciplines (Damian, Marczak et al. 2007; Fitsilis, Gerogiannis et al. 2009). Nowadays performance measurement has become more crucial and complicated with the increase of virtuality in construction projects.

AUTHORS ***and YEAR***	**PAPER** ***in CONFERENCE***	**THEORETICAL CONTRIBUTION**	**UNITS of ANALYSIS**	**ANALYSIS** ***via SOFTWARE NETWORK METRICS***
Priscilla, A. *2007*	Redefining and Measuring Virtual Work in Teams: An Application of Social Network Analysis *in HICSS'07, IEEE*	Provides the use of SNA as a tool to measure virtual work scope, an individual's level of virtual work practice in teams.	Sample communication relations of different individuals who practice virtual work	Level of virtual work, ego analysis, e-contact ratio, e-frequency ratio,
Damian, D., Marczak, S., Kwan, I. *2007*	Collaboration Patterns and the Impact of Distance on Awareness in Requirements-Centered Social Networks (RCSN), *in RE, IEEE*	Provides the use of SNA and the concept of RCSN to analyze collaboration and awareness of other members working on interrelated requirements.	A requirements-centered team (RCT) as a cross-functional team in which each member is involved in a particular stage of a requirement's development	Centrality, network similarity
Fitsilis, P. Gerogiannis, V. Anthopoulos, L. *2009*	Using social network analysis for software project management *in CTIT, IEEE*	Provides a framework for software project analysis in order to enrich the current ability to measure project performance and an exploration of the use of SNA as a method to improve software project control	15 agents working on three different software projects	Betweenness, degree and closeness centrality, *via ORA*

Table 5: SNA Research in Performance Evaluation

SNA can capture the virtual work that is done to accomplish tasks by identifying the contacts of each member and frequencies (Priscilla 2007). SNA provides quantitative data on existing collaboration patterns between the project participants. The ratio between the physical communication and electronic communication can facilitate determining the efficient percentage of virtuality during the building design process. The type of the electronic communication between the team members can be identified and also analyzed to find out the effective types of communication in order to accomplish tasks. The ability to compare the types and the amounts of communication will contribute to the performance measurement of virtuality in construction projects and examine the effects of who to connect whom via what type of communication on the project outcomes (Priscilla 2007).

4. CONCLUSIONS

SNA provides an important quantitative approach for the construction industry. This paper presents a comprehensive review of the SNA studies in construction. Findings imply that SNA is used commonly to analyze communication and collaboration issues in construction research. A series of centrality measurements are conducted for the quantification of the interconnectedness of actors in the industry. Additionally, network density and centralization that enable researchers to uncover structural properties of the whole network are reported.

Advances in SNA research emphasize that there is more potential for SNA studies in the construction industry. With the recent developments in telecommunication and information technologies, virtual teams have widely emerged in the construction industry as well. Participants from different disciplines, organizations and even countries utilized technological innovations to collaborate irrespective of their physical locations. These novel design and construction teams use virtual collaboration tools such as e-mail, teleconference, videoconference, and virtual workspaces. Adoption of BIM technology has also become an inter-linkage of construction project actors. It might be possible to discover interaction patterns of the virtual construction teams via SNA augmented BIM. The project manager can monitor each member's performance in the network and could easily assign specific tasks and roles. Automating SNA in a BIM environment could provide a solid decision support system and even self-regulation for the realization of the whole network. The inferences both at the organization level and individual level might make it available to examine the optimal level of virtual communication to form a high-performance construction team.

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CONSTRUCTION SITE DESIGN: A SYSTEMATIC APPROACH

Prof. Dr. Marco Lorenzo Trani
A.B.C. Department, Politecnico di Milano, Milan, Italy, marco.trani@polimi.it

Benedetta Bossi, M.Sc. Arch.
A.B.C. Department, Politecnico di Milano, Milan, Italy, benedetta.bossi@polimi.it

Massimo Minotti, M.Sc. Eng.
Research Consultant, Milan, Italy, info@minottires.com

Abstract

The paper presents a proposal coming from an applied research on the site dealing with the construction site designs that lasted several years. Having assessed some recurring lacks during the execution phase of a construction or of a recovery process, as pointed out also by several investigation reports and studies, a disciplinary reorganization has been taken into account, also considering the recent Italian regulations about the design, the execution and the management of the contracts – both public and private – and, last but not least, those concerning the health and the safety in the workplaces. Despite the legislation statements, the progressive growth of the attention in the construction sector for site design and for the health and safety planning has been in most cases approximate and, above all, it has been addressed as an "appendix" of the of the other design disciplines (architectural, structural, etc.). On the contrary is spelt out that design, organization and management of a construction site, if they are correctly set and applied, not only they cut down the injury risk, but also they improve significantly the qualitative and the economic performance of an intervention. For this reason the research has been carried out on the reorganization of the design discipline related to the construction site and states a clear identification of its structure and aims, describing its different phases, levels, systems and subject areas.

Keywords: Construction site, Design phase, Execution phase, Health & Safety.

1. INTRODUCTION

From a legislative point of view the ergo-technique design has assumed a strategic value after the promulgation of d.lgs. 9 April 2008, n. 81 (transposition of Directive 92/57/EEC), concerning Health and Safety on workplaces, and of the d.P.R. 5 October 2010, n. 207, concerning Public contracts Regulation. In particular in these laws Health and Safety became a strong requirement of construction site design and so designers need designing for construction health, safety and ergonomics competencies (Goldswain and Smallwood, 2011) because they are legally required to consider working conditions in their design. Despite this, there has been little research on how health and safety aspects can be interactively integrated during the design and preparation phase (Gangolles et al., 2010). Moreover, studies have shown that designers in general are not able to satisfy this obligation (Behm, 2005; Frijters and Swuste, 2008) and some earlier researches have indicated that safety planning and control methods need to be improved even beyond what is required by regulations and standards (Saurin, Formoso and Guimaraes, 2004). Besides, not only designers but also construction companies need tools to have a "better yard" and achieve the safety requirement, for example applying the D.Lgs 231/01, that gives the opportunity to the employer to have protection on administrative liability thanks an appropriate "model of organization and management", as outlined by Trani and Manderioli (2011). So the research puts its effort in studying new methods and tools to help site designers in the design, organization and management of a construction site and so to reach the higher health and safety standards requested by the law. Even more, the study has led to the introduction of the ergo-technique information idea as key-factor in helping site designers. Workers' Health and Safety Cluster researchers team at Politecnico di Milano allowed some of its members - involved in construction workplaces design and management- to achieve a more conscious approach to construction site design that leaded into the exigency to point out and solve the "construction phase problem" in an even more systematic way. The research, however, has deepened the study of the construction site design implementation in a civil or building project from the client point of view as well as from the contractor.

2. THE ERGO-TECHNIQUE DESIGN

Construction works include a wide range of activities related to new buildings and infrastructure as well as their rehabilitation (UNI 8290, ASTM E1557). To reach the target of the study, Architectural or Civil Engineering (ACE) projects have been subdivided, for simplicity, into three temporary macro-phases: the design phase, the tendering-award phase and the execution phase. The execution phase of an ACE project has to be supported by a design activity – the ergo-technique design or, more currently, the construction site design – lasting for the whole duration of the project, from the concept to the handover of works.

2.1. Contract Design and Production Design levels

In order to reorganize the design discipline related to the construction site, the temporal phases above-mentioned of the ergo-technique design – which find a legal basis in the legislative apparatus concerning health and safety in the workplaces – have been identified as *ergo-technique contract design* and *ergo-technique production design*. Following the design structure of the Public contracts Regulation, the ergo-technique contract design is subdivided in the three typical levels of an ACE design: *ergo-technique preliminary design*, *ergo-technique definitive design* and *ergo-technique executive design*. The ergo-technique production design, vice versa, is composed by two deepening levels: the *ergo-technique general design*, which returns the actual production setting, and the *ergo-technique complementary design*, which analytically investigates the operational procedures to be effectively realized and that includes any reference useful to the prevention and protection devices that have to be implemented.

2.2. Pre-Design and Execution Design activities

In the proposed structure, the ergo-technique contract design correspond to *construction site pre-design activity*, where the performance specifications of the site are formulated, while the ergo-technique production design takes the form of the *construction site execution design activity*, therefore characterized by the technical specifications that are able to satisfy the performance specifications posed in the previous phase. These specifications, if respected, allow the achievement of the expected level of site quality and safety (see Table 1).

Phase	Activity	Purposes	Levels	Results
Design	Construction site pre-design	Ergo-technique contract design	Ergo-technique preliminary design Ergo-technique definitive design Ergo-technique executive design	Tender
Execution	Construction site execution design (technical specification)	Ergo-technique production design	Ergo-technique general design Ergo-technique complementary	Works handover

Table 1: Sequence and characters of the ergo-technique design

3. CONSTRUCTION SITE SYSTEM

The contents of the construction site pre-design, nowadays, could have a dramatic impact on the design process, being able to improve its performance significantly, in order to fix and respect the milestones of the whole project related to time, cost and safety. For that reason it is necessary to postulate the definition of the construction site process as a "structured and organized set of all the acts – decision-making and operational – which carry out an architectural or a civil engineering work, in the context of an assigned place, according to a given global design". Furthermore, while the ergo-technique design -general understood-ends at certain stage of the work implementation, the construction site process continues until the handover of the works. It is then necessary to find a system able to carry out the construction site process, by postulating the definition of *construction site system* as the “integrated set of constructive functions linked together by relationship conditions - technological and spatial- aimed at the realization of the designed works in a given territorial-spatial location through the use of appropriate technological, material and human resources”. So, the ‘systemic approach’ to ergo-technique design creates a relationship between the technological and the spatial needs which must be satisfied in order to ensure the execution of the work activities in the best operative and safety conditions for the workers. This means that every aspect of the construction process must be analyzed by two points of view: technological-productive and spatial. In the first case, the designer must answer the question of ‘what is necessary to carry out the constructive function’, while in the second case he must answer to the question regarding ‘the place where the constructive function is carried out and what spaces are needed’. From this derives that the *construction site system* is the supra-system of a *technological-productive system* and of a *functional-spatial system*; the first corresponds to the set of all technical components (products, equipment, utensils, etc.) necessary to carry out the constructive functions, while the second is composed by the spaces in which these functions find their application.

3.1. The Technological-Productive System

The *technological-productive system* of the construction site has therefore the function to locate and order the characteristics and the technological components of the construction site system starting from the production, environmental and safety requirements related to the execution work. Moreover the technological-productive system is divided into five subsystems: logistic, infrastructural, plants, productive and temporary works. The *logistic subsystem* is formed by the complex of structures (liveable containers, available rooms, etc.) equipped in order to be used as office, meeting room, toilettes, dressing room, refectory and by the structures, equipment and kit for stockpiling and storage of the products and the equipment necessary for construction. The *infrastructural subsystem* is composed: by the system of manual handling or, more in general, of the pedestrian workers’ flow, by the mechanized handling system, by the air handling system and by all those elements that can be related with handling for access operations, manoeuvre, parking, loading and unloading of materials and machines to be used to carry out the project. Instead, the *plant subsystem* is the structured set of the works and services necessary to use and supply every form of energy necessary to perform the works and to exploit and disposal of the site fluids (*e.g.* electrical system, grounding system, fire system, etc.). The *productive subsystem* is the structured set of the equipment and of the technical components for the preparation, laying, transformation, assembly or disassembly of products, temporary works or equipment (*e.g.* disk saw, concrete mixer, etc.). At last, the *subsystem of the temporary works* is the structured set necessary to define the separation of the construction site spaces (*e.g.* scaffoldings, banisters, etc.).

3.2. The Functional-Spatial System

The *functional-spatial system* of a site has the function to point out and order the features and the spatial elements of the site system, starting from the spatial-operational and safety requirements related to a work execution. It has been defined as the "structured set of the spatial subsystems associated with the constructive functions and the operational sequences of a construction site process to be done in each spatial element". The spatial subsystem of a site (workplace) is given by the aggregation of spatial elements (workstations), also not adjacent, intended to accommodate a working.

3.3. Areas of the Construction Site Pre-Design

CONSTRUCTION SITE PRE-DESIGN (during project design phase)
Project Contextualization
Functional-spatial design (productive site)
Technological-plant design (productive site)
Process analysis (construction phase)
Process planning (construction phase)
Organizational modeling
Health & Safety Coordination planning
CONSTRUCTION SITE EXECUTION DESIGN (during project execution phase)
Site organization
Site operational management
Production operational design
Operational safety planning

Table 2: Structure of the ergo-technique design

The contents of the ergo-technique design belonging to the different stages and design levels outlined above may in turn be organized in a series of design themes, uniquely characteristic for each intervention, from the point of view of their disciplinary field (Table. 2).

3.3.1. The Project Contextualization

In the ergo-technique design it is the area that identifies the features that affect the execution phase of a building process – generated by the intrinsic characteristics of the production site and by the impact of the construction site on the same – and it evaluates the relative criticalities (Turchini and Trani, 2008).

3.3.2. Functional-Spatial and Technological-Plant Design

The *functional-spatial design* identifies the spatial elements of the site system, outlining its characteristics, the quantities, the location and the mutual relations in order to satisfy the operational and safety needs of the site. The *technological-plan design* identifies the productive elements of the site system, defining the functional and technical characteristics in order to satisfy the production, environmental and safety needs. This area was investigated in an integrated way also by Shabtai , Mohsen and Farnaz (2012).

3.3.3. Process Analysis and Process Planning

The *process analysis* describes the phases of the production process necessary to the realization of the individual portions of the works, indicating the necessary human, material-technical resources. The *process planning*, instead, elaborates the timeline of the actions necessary for the realization of a building-civil engineering work, establishing the time and the mutual bonds of precedence, relating to the safety of the workplaces.

3.3.4. Organizational Modeling and Health and Safety Coordination Planning

The *Organizational Modeling* defines and regulates the type of contract, the legal entities and the responsibility of all the project actors. In the end, the *Health and Safety Coordination Planning* integrates the operational, organizational and management models of the intervention in order to protect the health and safety of the involved human resources.

3.4. Areas of the Construction Site Execution Design

The *site organization* is the area that concretizes the assignment of the spatial and technical resources on the basis of the site functional spatial and technological-plant pre-design. The s*ite operational management* is the area that integrates in the ergo-technique design of production the relational and interaction modalities between the different actors involved in the production (contracting and sub-contracting firms, self-employed persons) or in the provision of the technical and material resources necessary for the site (retailers, manufacturers, rental companies), at each level (managers, supervisors, workers).

The *production operational design* is the discipline that assigns, for each site activity, the procedures and the operating instructions in accordance with the process analysis postulated by the construction site pre-design, complementing it. Finally the *operational safety planning* integrates in the operating production design the functional model of workers' site prevention and protection, by identifying all potential material agents of accident and/or pathogens present in each single production cycle.

4 SITE DESIGN IN PUBLIC WORKS

In the Italian low the design activities are divided into three successive levels: preliminary, definitive, executive. The documents produced in the three levels are anticipated and guided by the pre-design document, drawn up by the Public Project Supervisor. In general it's possible to say that the pre-design design document as the design of preliminary level are unlikely submitted to the executrix firm during negotiations.

4.1. Preliminary Ergo-technique Level

This level, defined as the design for the client, identifies the qualitative and functional characteristics of the works to be performed and the needs specific services. From the point of view of the ergo-technical design, the site designer must provide the first indications and measures for the protection of health and safety in the workplaces.

4.2. Definitive Ergo-Technique Level

This level, defined also as the design for the Authority, identifies the works to realize and it contains all the necessary elements for the granting of permits and required approvals. This design level assumes the constraints and the guidelines established by the preliminary design. From the point of view of ergo-technique design, in the definitive phase the designer must perform an update of the document containing the first indications and provisions for drawing up the safety plans realized during the preliminary phase and he must provide an economic framework.

4.3. Executive Ergo-Technique Level

Finally, this level, prepared in accordance with the definitive design, it determines in detail the work to realize and the relative expected cost and it must be developed to a level of definition such as to allow that each element is identifiable in form, typology, quality, size and price. The executive design also includes the special performance or descriptive contract and the maintenance plan. From the point of view of the ergo-technique design the Safety and Coordination Plan and the labor rate table must be provided. At last, the law provides the list of the design documents that are the contract package of the executive design and a brief description of their contents (general and specialist reports, drawings, calculations of structures and plants, safety and coordination plans, etc.).

5 CONCLUSIONS

The research was carried out on the reorganization of the construction site design discipline, identifying its structure and aims, describing its different phases, levels, systems and subject areas. The proposed organization has the aim to help designers and firms in the design, organization and management of a yard, achieving also the goal of health and safety issue, starting from the preliminary phase design. In the opinion of the research team a lot of work have to be done, in particular regarding the definition of site requirements, even if some studies about its performances have been started (Trani and di Melchiorre, 2005).

With further developments of the research it is hoped that in the future it is possible to study a standard that defines what is the construction site design in its different steps, identifying univocally its contents.

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THE INTERACTIVE SYSTEM FOR IMPLICIT LEARNING OF PROJECT MANAGEMENT IN CONSTRUCTION

Leonas Ustinovichius
Vilnius Gediminas Technical University, LT-2040 Vilnius, Lithuania, leonas.ustinovicius@vgtu.lt

Romas Rasiulis
Vilnius Gediminas Technical University, LT-2040 Vilnius, Lithuania, romarasi@gmail.com

Tatjana Vilutienė
Vilnius Gediminas Technical University, LT-2040 Vilnius, Lithuania, tatjana.vilutiene@vgtu.lt

Abstract

The considered system will be developed based on the main principles of learning systems. The methods of learning embrace the study of a theoretical course, the solution of real problems, their gradual complication, demonstration of the learner's mistakes and the control of the acquired knowledge.

Keywords: interactive learning system, computer database of knowledge, effective project management, solution classifications.

1. INTRODUCTION

In most areas of professional activities, university education is merely a basis for further development of a specialist. A young manager, unlike mathematicians who can solve complicated problems at the university, possesses only theoretical knowledge. The manager's skills of solving practical problems are being formed during a long period of practical work. It may be accounted for by the nature of practical management problems, which, unlike mathematical problems, do not have a single solution, and the solutions themselves are subjective. A specialist most proficient in his/her area is considered to be an expert. As shown by the investigations in cognitive psychology, it takes a beginner at least 10 years of intense practical work to become an expert [Ericsson and Lehnmann, 1996; Ericsson and 1996]. If practice is not sufficiently intense, the period for the required skills' development is even longer. Therefore, the systems of implicit learning are primarily aimed at intensifying practical work for beginners in management.

The solution of construction problems often requires the analysis of the available alternatives under uncertainty conditions. This particularly applies to the solution of organizational and management problems in construction [Liaudanskiene *et al.* 2012].

Behavior investigation of the experts and the beginners has shown the considerable difference in solution finding strategy while solving diagnostic tasks. It was shown that the beginners mainly use so called "reverse conclusion", which means that the beginners are looking for the arguments for all the possible versions of solutions. In this case more time is wasted for the false answers. The experts though use so called "straight conclusion" method, which means they go straight from the task to the solution without running through multiple versions. And that task solving method seems to be the right and quick in most of the cases [Groen and Patel, 1988; Patel and Ramoni, 1997].

The straight conclusion in fact is the knowledge process that could be modeled using some code of decisive rules [Kihlstrom, 1987]. Although the principle trouble here is to get those codes of decisive rules that describe the whole concept of task solving strategy from the experts. Usually the experts can couch the decisive rules only for simple and evident cases.

Not being able to verbally express the task solving strategy leads to the conclusion that main part of the skills expert keep in subconscious level. Investigation of the subconscious skills showed that appearance and perfection of them appear in the process of continuous and intense practice. Even if the personal abilities of the student are important the "10 year of practice" rule stays complete.

Usually there are two types of subconscious skills [Berry, 1987]. First type - initially has the visual, declarative imagination that as the result of intensive practice is used automatically with no attention focus or thinking [Fitts, 1964; Anderson, 1982].

Second type of subconscious skills is different initially for not being able to be shown neither visually nor in declarative way. This type of skill is possible only as a result of practice which in this case is the main part of tuition by correspondence process.

Continuance of building up the expert skills is the main task to make that period of time shorter by creating new computer technologies that will be able to make copies of expert knowledge and teach new specialists [Kaklauskas *et al*. 2013; Tupėnaitė *et al*. 2010; Zavadskas and Turskis, 2011].

2. MAIN CHARACTERISTICS OF TUITION BY CORRESPONDENCE

2.1. Subjective audience of tuition by correspondence systems

Lack of intensive practice extends the expert skills formatting time. That is the case why tuition by correspondence systems initially are assigned for the beginners and to intense the practice. For example, management taught by managers is based on their personal experience. And to reach their expert level they manage to make a lot of mistakes. Each mistake can crash down the project. To diminish this factor young manager go through a very long practice period authorized by skilled managers to adjust their false decisions.

However, practice intention at management and some other grounds is determined not on students will but on purity of the emerged diagnostic task. For example, some situations emerged in practice are explicitly dangerous. Young doctors as a result simply get no chance to get high level in diagnosis. Tuition by correspondence systems solve this problem.

Besides, there are another category of the “rookies” that the traditional way of teaching makes no effect on them. Usually they are engineers with big experience of other grounds. In this case tuition by correspondence is irreplaceable. Educational computer system of tuition by correspondence for diagnotical skills will reduce the time for the young specialist to gain needed skills.

2.2. The basic ideas of the learning system

The suggested interactive system of implicit learning includes all the above-mentioned features and may be used for raising the qualification of specialists at the advanced training courses or by self-education and for qualifying evaluation of managers [Larichev *et al.* 1991]. To develop a computer-aided system allowing a young specialist to acquire the expert’s skills, two problems should be solved:

1. To create a computer database of knowledge (skills) precisely simulating expert knowledge.

2. To instruct the beginner how to solve practical problems as effectively as an expert does it.

To solve the first problem, expert classification approach, allowing for developing a database of comprehensive and consistent knowledge in some special areas was developed. This approach may be applied to a set of problems, where an expert attributes various objects to different classes of solution (classification problems).

When a method of presenting expert knowledge in the concise from is found, the problem of effective learning of project management may be solved. The aim is the subconscious creation of some rules in the learner’s long-term memory, allowing him/her to make decisions, which are as effective as the decisions made by an expert. The idea that the efforts should be made towards helping learners to “grow” these rules by themselves, rather than trying “to pass” them to learners, is crucial for implicit learning. For this purpose, they should be given a number of problems without the rules of solution used by experts. It should be emphasized that the suggested approach is based on the creative analytical process, when learners analyze their solutions and compare them with those of an expert. In this way, the creative thinking of learners, helping them to consider the problem of effective project management from various perspectives, is developed.

2.3. Attainment base disposition

Classification of the experts was implemented to solve the first task [Larichev *et al*., 1991] which allows making basis for full and no reluctant knowledge in separate professional grounds. This approach is designed for certain round of tasks where the expert label different objects to different solution classes (solution classifications). Lets reconsider the official task form in the ordinal classification.

Submitted:

1. *G* – is the property satisfying the target criterion of the problem;
2. $K = \{K_1, K_2, \ldots, K_N\}$ – is a set of evaluating criteria of an object;
3. $S_q = \{k_1^q,\ k_2^q, \ldots, k_{\omega_q}^q\}$ for $q = 1, \ldots, N$ – is a set of estimates based on the criterion K_q;

ω_q – is the number of graduation marks on the scale of the criterion K_q; the scales S_q are arranged in the order of distinctness of the property *G*.

4. $Y = S_1 \times S_2 \times \ldots \times S_N$ – is the spatial arrangement of the objects to be classified. Every object is described by a number of estimates based on the criteria $K_1, \ldots, K_N$. In this way, a set of alternatives $y = (y_1, y_2, \ldots, y_N)$ is defined, where

$L = |Y| = \prod_{q=1}^{N} \omega_q$ is cardinality of a set *Y* (the number of alternatives).

5. $C = \{C_1, C_2, \ldots, C_M\}$ is a set of classes to be obtained by breaking down the set Y^a, which should be arranged in the ascending order of distinctness of the property *G* (in the class C_{n+1} this property is more distinct, while in the class C_n it is less distinct).

We input the binary strong dominance approach:

$$P = \left\{ (\boldsymbol{x}, \boldsymbol{y}) \in Y \times Y \middle| \forall q = 1 \ldots N \quad x_q \geq y_q \quad u \quad \exists q_0 : x_{q_0} > y_{q_0} \right\}. \tag{1}$$

It is not that difficult to replace it because it is antireflective, asymmetrical and transitive.

Required: to make a portrait with experts helping $F : Y \to \{Y_i\}$, $i = 1 \ldots M$, such as $Y = \bigcup_{l=1}^{M} Y_l;\quad Y_l \bigcap Y_k = \varnothing,\ \text{при}\ k \neq l$ (where Y_i –multiple vectoring rating C_i class rank), satisfying consistency:

$$\forall x,y \in Y : x \in Y_i,\ y \in Y_j,\ (x, y) \in P \Rightarrow i \geq j\ . \tag{2}$$

This way the purpose of the classification task is to allocate *L* objects into *M* solution grades. If the object with characteristics closer to *G* rank of values can not belong to the *G* class because of its lower expressive quality grade the classification is maintained as no contradictive.

First, an expert and an engineer, cognition science specialist, make a description of the considered professional area, based on a set of criteria (indicators), describing the objects analyzed (the state of the managed project) and defines the sets of the possible values of these criteria. Then, the classes of solutions are determined, based on the type of the particular problem associated with a particular project. Along with classification, the information elicited from an expert is checked for random errors (testing for consistency), and the combinations of criteria not encountered in real conditions are determined. The latter could help reduce the number of the cases to be considered. When the method of presenting the expert knowledge in a concise from is found, the problem of effective learning of management may be solved. This process is aimed at subconscious creation of the rules in the long-term memory of a young specialist, allowing him/her to make decisions in the way an expert does it. Successful learning requires the development of special methodology for solving the given problems. The experience in creating the effective systems for acquiring procedural knowledge allowed for formulating the well-known eight principles of learning systems as follows:

1. To model the learners based on a set of products.

2. To inform the learner about the structure of sub-tasks, this should be performed for solving the problem.

3. To use real problems in learning.

4. To help learners to form general notions, based on the knowledge obtained in solving some particular problems.

5. To minimize the loading of the short-term memory.

6. To ensure prompt reaction to the learner's errors.

7. To change the details of the studied material, depending on the learner's progress.

8. To allow the learner to develop the particular skill's components.

The methodology of learning project management has the following main features:

1. A theoretical course of project management. This course is relevant because, first, practical learning is hardly possible without theoretical knowledge and, second, it helps learners 'to enter' the professional area.

2. Provision of a set of real, practically encountered problems. This approximates the considered system of learning to the real process of knowledge acquirement by experts. Moreover, this approach increases the interest of learners in the suggested system.

3. Gradual complication of the problems, depending on the progress of learners. The method of dividing the problems according to their complexity will be described below.

4. Demonstrating to a learner his/her errors and explaining the right solution. This helps the learners better remember the problems as well as making the process of learning more interesting to them.

5. The control of the acquirement of the material by learners. This actually helps to construct the learner's model, allowing for checking his/her errors and showing the gaps in his/her knowledge. The process of learning may be complicated only when these gaps are eliminated.

Proposed tuition by correspondence system will include the entire upper mentioned attributions and can be used at qualification raise or self education or testing manager during certification.

Training is carried out as follows. The trainee takes the telltale test that will show his knowledge level which is taken as equal to the correct task solution percent. After that the trainee takes the course of theory to keep the main principles operating the project updated. Then he/she constantly gets new situations where he/she must choose the right solution out of few given. Educational system gives the comment to the experts' solution if the trainee chooses the wrong one (the solution that is different from the experts' solution). If the trainee chooses the right solutions to the certain amount of tasks, the system will raise the level of the difficulty. When the trainee makes a lot of mistakes solving the task, the system lowers the level of difficulty. The training is finished only when the trainee learns to solve the highest level of tasks. At the end of the training the trainee is taking one last task to assure his/her practice diagnostics development.

2.4. Task difficulty determination

The expert makes his/ her own ensuring rules based on his/her own experience in life solving different kind of tasks of his/her own subject ground. In many cases he/she goes from the easier to the complex rules. It is logical to make the training system the same way – starting training with the easyer tasks and progressively making tasks more dificult.

The difficulty of the tasks technically can be identified by the ground between pointed situation and bound of two adjacent solution classes. As the result most of the situations divide into different difficulty layers (see the figure No. 1) in which case the less difficult situation will appear far away from the bound and the most difficult – close to the bound of adjacent solution classes. The most difficult situations appear on the bound either for the trainee or the expert.

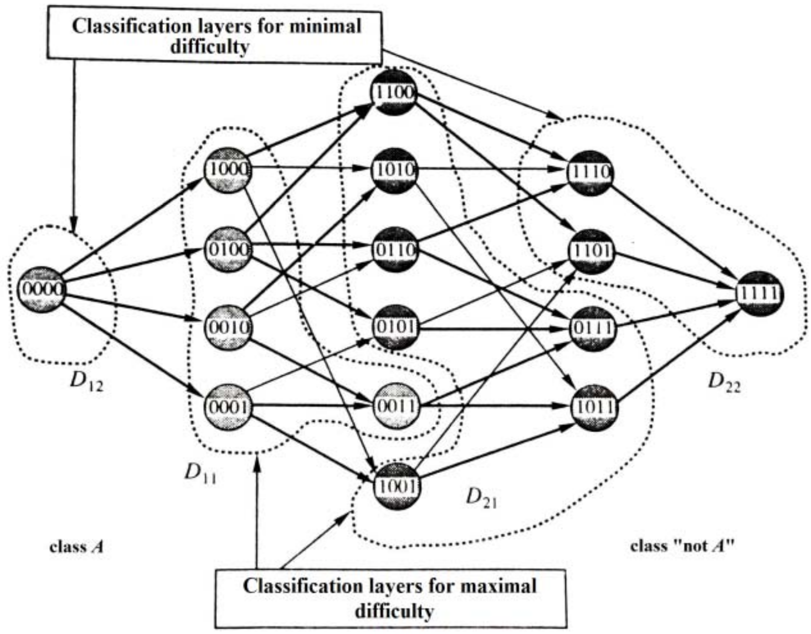

Figure 1: Classification layers for the different difficulty objects

This official difficulty level separation according the distance to the bounds does not always work in practice because different indications have different importance for diagnosis. That is why some of the tasks must be hand held to the lower or higher difficulty level of the system.

2.5. Choice of the real tasks

Surreal situations (with the reluctant meaning of evidence) are already discarded out of the process of preparing education basis. This education basis will contain only real life situations. However part of the situations in this basis cannot be used for training even if they fit into making and expert consulting system.

The experts have the ability to solve the tasks fast and "straight" as it was pointed out before. However, as practice shows experts without knowledge state can use the "backward" strategy (consideration) for the situations that are rear in real life. Situation can be difficult to solve even for the experts still because the certain situation can be delivered as a model with the lack of information. Besides, there were many literature described cases when experts made mistakes being "affected by the last case". In this case each expert can be in "unstable knowledge" zone that can misrepresent and compound the main rules and negatively rebound the training.

Never the less unstable knowledge training has any sense as the lack of stability leads to the experts' questioning and controversy of the situation.

The problem is how to differ stable and unstable knowledge. Together with Mr. Podlipskiy we indicated the hypothesis that the experts keep in their minds not the rules to identify the classes but the rules how to label the situations to certain classes. We tested this hypothesis of two classifications on one set. On the first classification we pointed out the first class, which means that the solution classes where- "Class A" and "all the rest". On the second case – "Non class A" and "all the rest". In between the "Class A" and "Non class A" a thin layer of unstable cases was formed.

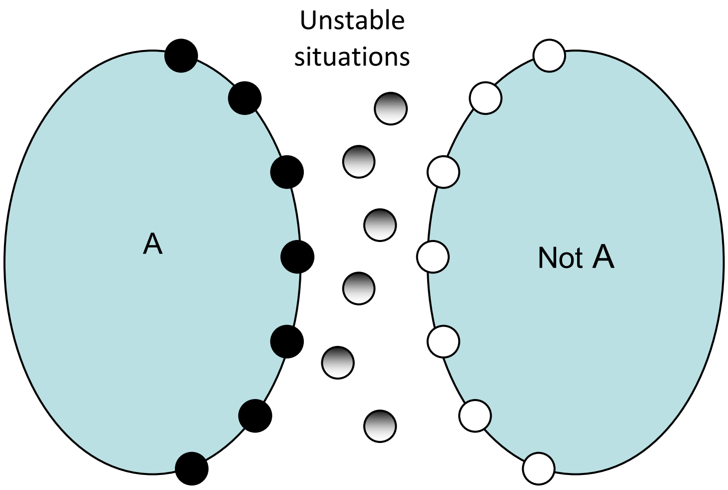

Figure 2: Instability of knowledge within bounds of calsses

Using this kind of double classification based on this hypothesis more stable experts' knowledge can be identified. But this ground needs detailed testing.

3. CONCLUSIONS

Here we pointed out the main ideas how to build up an intellectual computer system for technical expert knowledge training and how to develop these ideas in developing this kind of a system.

This kind of a system can be used not just to train young specialists but to develop experts with life experience on other grounds(close to the certain ground experts knowledge) who will be able to get the diagnostically education using less time for training and making less fateful mistakes.

New computer technologies make new type of university education possible – young experts can have not just technological education but are capable solving practical tasks.

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APPLYING TAGUCHI GAS IN CONSTRUCTION PROJECT AUDIT ASSIGNMENT PROBLEMS

Yu-Ren Wang
National Kaohsiung University of Applied Sciences, Kaohsiung, TAIWAN, yrwang@kuas.edu.tw

Tsai-Hsun Lin
National Kaohsiung University of Applied Sciences, Kaohsiung, TAIWAN, yily330@gmail.com

Yi-Fan Shih
Taiwan Province Professional Civil Engineer Association, New Taipei City, TAIWAN, shih090202@kimo.com

Abstract

The main purpose of this research is to apply Taghchi - Genetic Algorithms to solve complicated construction audit project and auditor assignment problems. The Kaohsiung County Government has established an audit team to execute the quality audits for public construction projects. Under the government regulations, the members in the audit team select projects from a pool of hundreds of on-going public construction projects and assign corresponding quality auditors from dozens of qualified auditors to conduct quality audits. The audit team members are facing a very complicated assignment problem and it is normally solved by the “gut feeling” of the audit team members. Many times, the auditors do not have appropriate expertise to conduct quality audits for projects they have been assigned to and hence, the quality of the quality audit is in jeopardy. To assist with the quality audit team, this research proposes a decision support system based on Genetic Algorithms (GAs) to solve this assignment problem. In the mean time, Taguchi Method is applied to find the best combinations of parameters for the proposed GAs model. The proposed decision support system is validated with real project data from the Kaohsiung County Government, and the results show that the proposed model provides better audit assignments when comparing to traditional practice of “hand-picking”. The quality of the assignment results is judged by measuring how well the auditors’ background expertise matches the project characteristics. It is hope that the decision support system proposed by this research will help the members of the public construction project audit team in selecting projects for audits and assigning associated auditors. By doing so, the quality of the quality audits can be improved and in the long run, the quality of the construction project itself can be improved.

Keywords: assignment problem, construction quality audit, genetic algorithms (GAs), taguchi method.

1. INTRODUCTION

In order to improve the quality of the public construction projects, the Taiwan government has enforced a three-level quality management system since 1993. The goal is to promote the awareness of the importance of construction quality among all the participants in the public construction projects. The first level is the quality control system executed by the contractors. The second level is the construction quality assurance system implemented by the local government construction department. The third level is quality audit system enforced by the national government construction department (The Executive Yuan 1993). The structure of the three-level quality management system is shown in Fig. 1.

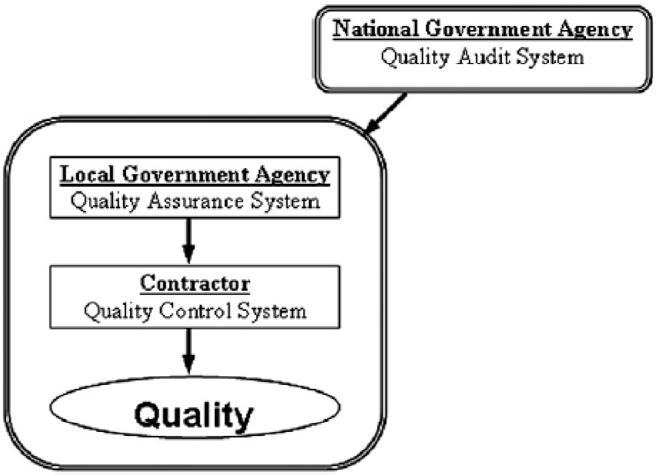

Figure 1: Three-Level Quality Management System

To conduct the third-level quality audit (quality audit system), a quality audit committee is established in the Kaohsiung County Office. The committee is composed of one chairperson, two vice-chairpersons, one secretary and five staffs, 17 internal auditors and 45 external auditors. The auditors are nominated by the committee and approved by National Construction Council. Approved auditors are either experienced experts (from government or from private sector) or knowledgeable scholars. The quality audit committee is responsible for selecting public projects to be audited and assign auditors for quality audits every month. In general, there are more than 150 construction projects in the list and eight projects are to be selected for audit each month. For each project, three auditors (one internal and two external) should be assigned from the approved auditor list. This is a complex assignment problem as there are a lot of possible project and auditor combinations (approximately 5.09E+29) to choose from. This is a very tough task for the quality audit committee and at times, the committee just randomly (or by gut feeling) selects projects and assigns auditors. As a result, some auditor expertise might not match the project characteristics well and thus the “quality” of the construction quality audit is in jeopardy.

To assist with this assignment problem, this research adopts generic algorithm to develop a public construction project selection and auditor assignment model that aims at finding optimal matches between the auditor expertise and project characteristics. In addition, Taguchi method is applied to assist with finding the appropriate parameters in the GAs model. With data provided by the Kaohsiung County Government, the model is proven to provide better recommendations regarding project selection and auditor assignment when comparing with traditional manual selection and assignment process. Built in the MS EXCEL environment, this model can be easily utilized by the members in the quality audit committee to assist with the public construction project quality audit process.

2. LITERATURE REVIEW

2.1. Assignment Problems

Generalized Assignment Problem (GAP) is trying to find the optimization of different combinations, which are concerned with assigning n jobs to m agents under constraints. Every agent has different capability and resource constraints. When performing each job, the cost occurred and efficiency achieved are different for each agent. The purpose of solving GAP is to assign appropriate agent to complete the n jobs so that the lowest total cost or the highest overall profit is achieved. It can be expressed in the following equations (Chu and Beasley 1997):

Maximize or minimize
$$f(x) = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \tag{1}$$

subject to
$$\sum_{i=1}^{m} x_{ij} = 1, \quad j = 1, 2, \ldots, n \tag{2}$$

$$\sum_{j=1}^{n} r_{ij} x_{ij} \le b_i, \quad i = 1, 2, \ldots, m \tag{3}$$

Equation 1 is the objective function and equations 2 and 3 are constraints. *n* is the total number of jobs to be performed and *m* is the total number of agent available to perform the jobs. C_{ij} refers to the cost occurred or profit obtained for agent *i* to complete job *j*. When X_{ij} equals one, it means that agent *i* is assigned to perform the job *j*. On the other hand, when X_{ij} equals zero, agent *i* is not appointed to perform the job *j*. r_{ij} is the resource consumed by agent *i* to perform the job *j* and b_i is the total resource available for agent *i*. Equation 2 makes sure that each job is performed by only one agent and Equation 3 makes sure that the resource consumed by each agent does not exceed the capacity limit.

This research intends to investigate effective techniques for assigning auditors and selecting projects for public construction audit under constraints. Several researches have been conducted to solve this sort of assignment problems with different techniques/algorithms, such as exact algorithms (Savelsbergh 1997; Narciso and Lorena 1999; Gomar et. al. 2002; Haddadi and Ouzia 2004), heuristic algorithms (Pearl 1984; Chu and Beasley 1997; Diaz and Ferandez 2001), and genetic algorithms (Holland 1975; Goldberg 1989; Michalewicz 1996; Ghani et. al. 2004; Toroslu and Arslanoglu 2007). The Genetic Algorithms is chosen for this research for its ability to find an optimum solution requesting only reasonable amount of trials. The basic concepts of genetic algorithms will be discussed in the following section.

2.2. Genetic Algorithms

First introduced by Dr. John Holland in 1975, the concept of Genetic Algorithm (GA) is based on Darwin's theory of biological evolution by natural selection (Holland 1975). GA is one of the optimization methods and is also an effective random search method. It adopts the principles of natural genetic evolution and selection process, by which traits that make it more likely for an organism to survive and successfully reproduce will pass on to successive generations in order to have offspring with "better-fitness" for survival. When encountering with complex problem, GA is able to search for optimal solutions by adopting this "best-fit survived" principle (Michalewicz 1996). Similar to the evolution by natural selection, the Genetic Algorithm searches for the best-fit solutions to a problem through a series of reproduction, crossover, mutation and selection process. Figure 2 below illustrates this process.

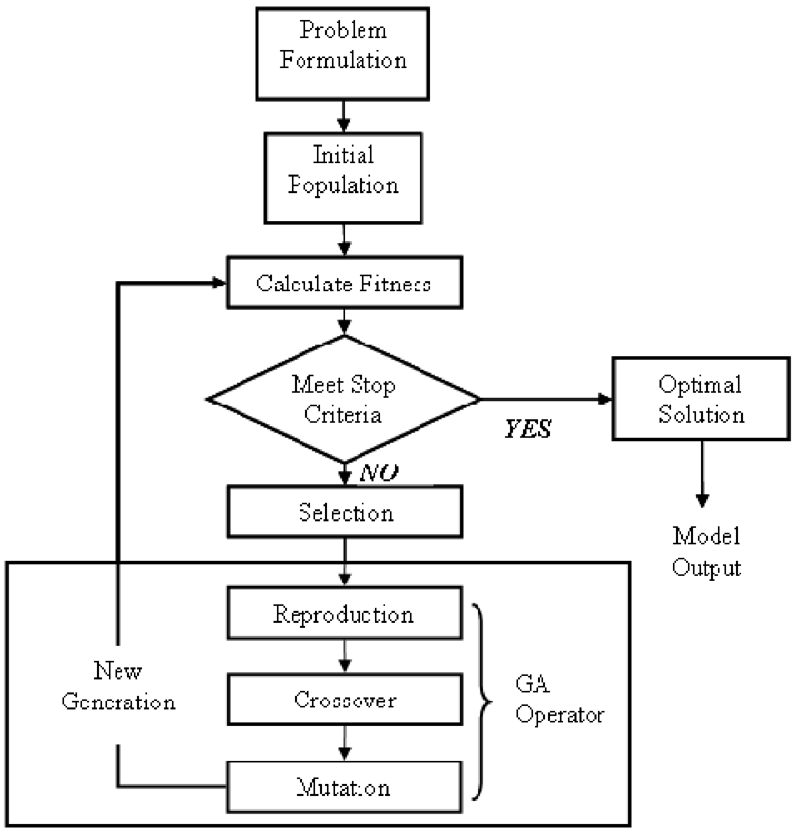

Figure 2: Genetic Algorithm Process

2.3. Taguchi Method

The Taguchi method, developed by Dr. Genichi Taguchi, involves reducing the variation in the process of design experiments. Using orthogonal arrays to test pairs of combinations, the Taguchi method allows for the analysis of many different parameters in the design process without a high amount of experimentation (Taguchi 1986). For example, a process with 8 variables, each with 3 levels, would require 6561 (3^8) experiments to test all possible combinations. However using Taguchi's orthogonal arrays, only 18 experiments are necessary, or less than 0.3% of the original number of experiments. In this way, it allows for the identification of key parameters and their relative design levels to produce designs with high quality products with low experimental costs.

The general steps involved in the Taguchi Method are as follows (Roy 2001):

1. Define the process objective, or a target value for a performance measure of the process.

2. Determine the design parameters affecting the process and the number of levels of variations associated with each parameter.

3. Create orthogonal arrays for the parameter design.

4. Conduct the experiments according to the selected orthogonal array to collect experimental data.

5. Complete data analysis to select control parameters and their optimum levels.

For its ability in finding key design parameters and their optimum levels with relatively few experimentation required, the Taguchi method has been adopted in different fields to optimize the parameters for end milling (Ghani et. al. 2004), cutting parameters for surface roughness in turning (Nalbant et. al. 2007), neural network model design parameters (Khaw et. al. 1995) and genetic algorithm model parameters (Chen and Chang 2007). For this research, the Taguchi design of experiment method is applied to find the optimum levels for the proposed genetic algorithm model.

3. MODEL DEVELOPMENT

The aim of this research is to develop a Genetic Algorithm model to assist with the selection of construction projects and quality auditors using the data provided by Kaohsiung County Government. In addition, Taguchi method will be applied to find optimal parameters for the proposed GA model. The model is developed in the MS EXCEL spreadsheet environment and the GA process is executed using Evolver™. This development process is discussed in the following sections.

3.1. Problem Statement

It is required by the Taiwanese regulations that to ensure the quality of the work, a minimum percentage of public construction projects must be audited by independent auditors. For example, the Kaohsiung County Construction Office has to select at least eight public construction projects and assign three quality auditors (one internal and two external) for each chosen project every month. On average, the Construction Office has approximately 150 projects and 62 registered auditors to choose from at any given month. In this case, there are more than 5.09E+29 different kinds of combinations to choose from. To assist with the project and quality auditor selection process, a GA model is proposed with an aim to find better match between project characteristics and auditor expertise. For a total of *p* projects, *m* internal auditors and *n* external auditors, the objective function for the proposed model can be expressed as follow:

$$Max \quad Z = \sum_{i=1}^{m} \sum_{\substack{j,j'=1 \\ j' \neq j}}^{n} \sum_{k=1}^{p} C_{ij(j')k} X_{ij(j')k} \tag{4}$$

where $C_{ij(j')k}$ is calculated by matching the auditor expertise and project characteristic weighting and $X_{ij(j')k}$ equals 1 when internal auditor E_i, external auditor external auditor F_j and $F_{j'}$ are assigned to project H_k.

3.2. Model Application and Parameter Setup

Information concerning auditor and project details is input into Excel and projects are numbered according to their project size. According to Kaohsiung County Construction Office, generally eight projects are selected for audit each month. The input variables for this proposed GA model are the eight chosen projects and 24 auditors (eight internal and 16 internal) selected for project audit. For model simplification, the project and auditor serial numbers are set as permutation variables in Excel. Since there are normally fixed number of projects and auditors selected each month, only the project and auditor serial numbers in predetermined cells have value 1 for decision variables (indicating chosen). The variable set-up in Excel is shown in Figure 3. In Excel, the fitness is obtained from summarization of product of project characteristic matrix and auditor expertise matrix.

For this particular model, four GA parameters are set as control factors to find the optimum GA parameter setup using the Taguchi method. These four GA model parameters are number of generation, population size, crossover probability and mutation probability. In addition, five predetermined levels are setup for each parameter and they are listed in Table 1. By applying the Taguchi method, the total number of experiments required to find the optimum values for these four parameters (each with 5 levels) will be reduced from 625 (5^4) to 25. These levels will be input into the Evolver™ during the model setup and execution. For that four factors (each with five levels) are chosen for this research, a standard Orthogonal Arrays L_{25} is chosen.

Project No.			Project Characteristics				Internal Auditor	Expertise				External Auditor	Expertise			
Above 50M	>10 M	>1M	Civil	Architecture	…	Landscape	Auditor No.	Civil	Architecture	…	Landscape	Auditor No.	Civil	Architecture	…	Landscape
1			H_{11}	H_{12}	…	H_{1t}	11	E_{11}	E_{12}	…	E_{1t}	32	F_{11}	F_{12}	…	F_{1t}
7			H_{21}	H_{22}	…	H_{2t}	14	E_{21}	E_{22}	…	E_{2t}	3	F_{21}	F_{22}	…	F_{2t}
8	27		H_{31}	H_{32}	…	H_{3t}	16	E_{31}	E_{32}	…	E_{3t}	43	F_{31}	F_{32}	…	F_{3t}
18	42		H_{41}	H_{42}	…	H_{4t}	6	E_{41}	E_{42}	…	E_{4t}	22	F_{41}	F_{42}	…	F_{4t}
17	33		H_{51}	H_{52}	…	H_{5t}	17	E_{51}	E_{52}	…	E_{5t}	42	F_{51}	F_{52}	…	F_{5t}
5	48	80	H_{61}	H_{62}	…	H_{6t}	15	E_{61}	E_{62}	…	E_{6t}	29	F_{61}	F_{62}	…	F_{6t}
9	20	86	H_{71}	H_{72}	…	H_{7t}	2	E_{71}	E_{72}	…	E_{7t}	26	F_{71}	F_{72}	…	F_{7t}
4	44	145	H_{81}	H_{82}	…	H_{8t}	7	E_{81}	E_{82}	…	E_{8t}	17	F_{81}	F_{82}	…	F_{8t}
6	32	105					8					33	F_{91}	F_{92}	…	F_{9t}
19	30	62					10					19	$F_{10,1}$	$F_{10,2}$	…	$F_{10,t}$
⋮	⋮	⋮					⋮					41	$F_{11,1}$	$F_{11,2}$	…	$F_{11,t}$
⋮	⋮	⋮					⋮					13	$F_{12,1}$	$F_{12,2}$	…	$F_{12,t}$
												44	$F_{13,1}$	$F_{13,2}$	…	$F_{13,t}$
												15	$F_{14,1}$	$F_{14,2}$	…	$F_{14,t}$
												12	$F_{15,1}$	$F_{15,2}$	…	$F_{15,t}$
												40	$F_{16,1}$	$F_{16,2}$	…	$F_{16,t}$
												9				
												2				
												⋮				
												⋮				

Figure 3: Project and auditor assignment matrix

Levels	0	1	2	3	4
No. of Generation	25	50	100	200	400
Population Size	50	100	150	200	250
Crossover Probability	0.1	0.3	0.5	0.7	0.9
Mutation Probability	0.1	0.3	0.5	0.7	0.9

Table 1: Control Factors and Level Figures

4. MODEL VALIDATION AND ANALYSIS RESULTS

The actual construction quality audit data from September of 2008 is obtained to calculate the fitness of the manual assignment and then the proposed GA model is applied to improve the fitness. According to the model setup, the fitness of manual quality audit assignment is 2,351 while most of the quality auditor expertise do not match project characteristics very well. In the mean time, the results from the proposed GA model show that the model is able to find corresponding auditors with expertise fully matching the selected projects and thus yields a better result with fitness of 4,894, a 106% increase comparing to manual assignment. The corresponding GA parameter setting are: (a) population in each generation set as 50, (b) cross over rate set as 0.5, (c) mutation rate set as 0.05 and (d) stopping condition set as less than 0.1% change in last 5,000 valid trials. It is clearly shown that by applying the GA model in the assignment process, the fitness value can be greatly improved comparing to manual assignment process. With better fitness value obtained, it shows that there is a better match between auditor expertise and project characteristics. As a result, the construction quality audit process can be improved.

After the model validation, Taguchi method is applied to examine the impact of these parameters with different levels and to find the optimum parameter setup. The best parameter setup obtained for this particular model is shown is Table 2. Further analysis shows that the first two parameters, number of generation and population size, have greater impact on the model output. The analysis results are summarized in Figure 4.

	No. of Generation	Population Size	Crossover Probability	Mutation Probability
Parameter Setup	4(400)	4(250)	4(0.9)	4(0.9)

Table 2: Best Parameter Setup

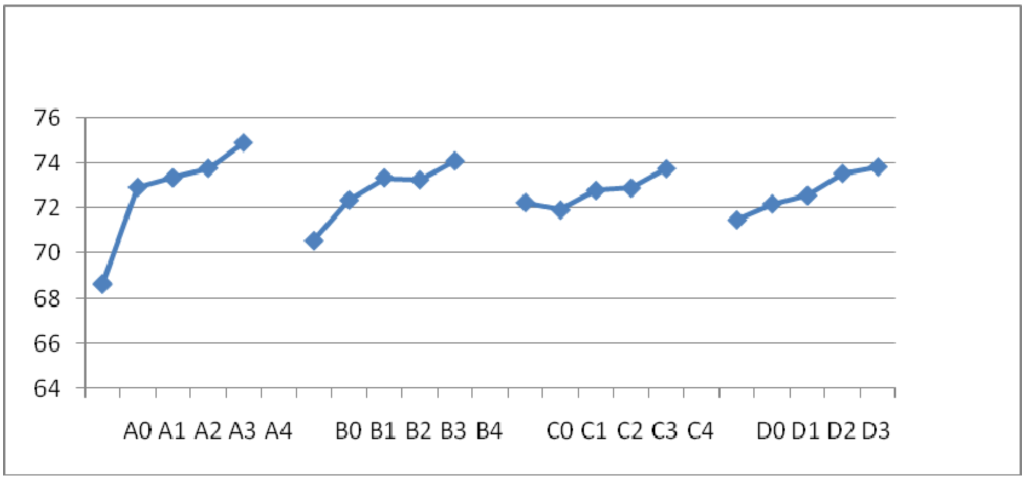

Figure 4: Taguchi Method Factor Response Matrix

4. CONCLUSIONS

To ensure the quality of the public construction projects, random third-party quality audits are required by the regulations in Taiwan. In practice, the project selection and auditor assignment is arranged manually by quality audit committee staffs. The manual selection process relies heavily on personal experience/judgment and oftentimes, the auditor expertise does not match the project characteristics well. In fact, this is a complicated assignment problem because for each month, there are typically more than 150 on-going projects and 62 registered auditors to choose from. In order to solve this problem, this research proposes a Taguchi Genetic Algorithm model to assist with the project selection and auditor assignment process. With actual data input from Kaohsiung County office, the model is tested and validated by comparing model outputs with to manual assignment results. The results show that the model outputs have a much better match between auditor expertise and project characteristics. In addition, Taguchi method is successfully adopted to find the most influential factors and optimum parameter setups for the proposed GA model. It is believed that with a better match between auditor expertise and project characteristics, the "quality" of the quality audit will be improved. In this research, the proposed Taguchi GA model is proven to be successful in solving the construction project selection and quality auditor assignment problem. Built in the Excel environment, this model can be easily adopted by public construction offices in Taiwan.

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THE ANALYSIS OF THE CONCRETE MIX DELIVERY ORGANISATION TO THE CONSTRUCTION SITE

Andrzej Więckowski, PhD

Cracow University of Technology, Krakow, Poland, andrzej@ztob.wil.pk.edu.pl

Abstract

The aim is to map interdependencies and describe the functioning of the delivery-unloading production cycle for concrete mix at the construction site. It presents the analysis of the variables (waiting time thresholds) and economics. It indicates rational technological solutions which fulfil the conditions for laying the concrete mix before it starts setting.

Queuing theory models were used in order to map the interdependencies and analyse the cooperation of transportation and production units (pumping team and concrete laying team). The following models were applied $M/M/1/\mathrm{FIFO}/N/\mathrm{F}$ for organisation I with transportation units working in closed cycle and $M/M/N/\text{-}/N$, for organization II for the so called *delivery directly after unloading (e.g. with automatic transfer of information using the* RFDI system from the construction site to the concrete-mixing plant).

The following results were obtained in the analysis of 750 m^3 of concrete, (transport distance – 7 km) built in the bridge span . Organisation II described with $M/M/N/\text{-}/N$ model is characterised by lower direct costs $K_{II,99\%}$ = 38.2 €/*d-u* [euro per 1 delivery-unloading]. N_{II} = 3 truck concrete mixers with 99% guarantee of not-exceeding delivery-unload time $\tau_{II,99\%}$ = 2.88 h (from pouring a batch of water into the cement till the end of the mixture pumping at the construction site). In those conditions average efficiency equals Q_{II} = 2.9 *d–u*/h. Whereas for organization I the results are accordingly: $K_{I,99\%}$ = 40.4 €/*d–u*, N_I = 4 and $\tau_{I,99\%}$ = 2.84 h, Q_I = 2.8 *d–u*/h.

Organisation II e.g. with RFID system is more advisable as it is characterised by shorter waiting time at the site (longer at the concrete-mixing plant). At the same time it increases working units efficiency compared to organisation I with self-regulating transportation units running in closed cycle.

Keywords: queueing theory, construction, production organization.

1. INTRODUCTION

Large distances between concrete plants and construction sites, as well as distortions in traffic of concrete mixers, cause variability in concrete mix transport time. Also, the time of pumping-laying the mix is not constant. Hence, the necessary waiting time, both on the part of the concrete laying brigade with the pump for transport of the mix, and on the part of vehicles queuing for the unloading procedure. In the case of concrete laying, in the case of each of the connected mix batches, the condition must be met that concrete laying and its monolithic connection with the surrounding mix (laid earlier or later) should occur still before the beginning of cement setting.

Standard analyses operate with site units (namely brigades or their selected parts, smaller teams, or even operators with the equipment) which, in the case of resignation from inter-operational storage, directly cooperate with the transport units. These are e.g. excavators collaborating with vehicles removing soil, or brigades with cranes erecting prefabricated elements continuously transported to the site. Usually, optimisation is oriented at minimising the cost of the works. In the case of works involving concrete, there is a need to lay and connect the mix portion still before cement starts setting. Therefore, an important element of the analysis involves determining the time passing from cement mixing with water at the concrete plant until its laying and connecting of each batch of mix at the site.

2. TYPICAL SYSTEMS IN THE QUEUEING THEORY

The work of teams comprising site units and transport can be described using Queuing Theory models. In such models, the queuing system represents functioning of the object rendering a service, e.g. operation of computer chip performing consecutive calculations, or at the site, the work of a concrete laying brigade with the pump for mix transported with vehicle-mounted concrete mixers.

Rich literature on the subject, e.g. [1,2,4÷8], includes analyses of many queuing systems, ‘open’ systems with infinite source of customers, and with the source limited to N units circulating in the closed system. The processes of arrivals and servicing can be described with both typical theoretical distributions, and with random distributions. There are systems with one or many parallel channels, with unlimited queues, or with “impatient customers” who do not join too long queues or resign from service in the event of too long waiting time.

In the case of cooperation between site units (e.g. a brigade with equipment) with transport units functioning in a closed cycle, which immediately after unloading at the site leave and carry out the next delivery, or in the case of loading the material (e.g. soil) immediately remove it and return for another portion to be carried out, the $M/M/m/$FIFO$/N/F$ queuing system is applied, Fig. 1.

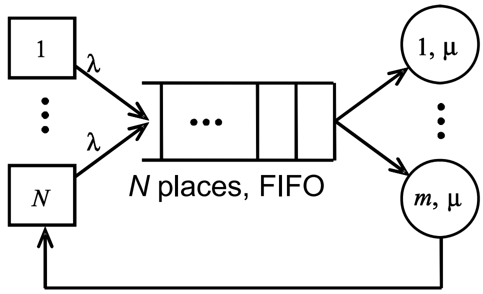

Figure 1: Concept diagram of the M/M/m/FIFO/N/F system

According to the notation by Kendall and Lee, such a model means a queuing system with Markov process related to the circulation time (corresponding to the time where the customer remains outside the system, that is time interval from the customer's leaving the system until his return to the system), and also with Markov process related to the servicing time, with the station featuring *m* service channels, queue according to the FIFO model (where customers are serviced in the order of arrival), and with *N* units functioning in a closed cycle *F.* The model, therefore, assumes that the processes of circulation and servicing meet the conditions of being stationary, memoryless and independent [1,2,4,5].

Furthermore, it was adopted that the intensity of stream of customers amounts to $\lambda = \frac{1}{\overline{t}}$, where $\overline{t}$ means average time of customers' remaining outside the system, and μ – intensity of the servicing stream, and where $\rho = \frac{\lambda}{\mu}$, $\rho < 1$.

When analysing the functioning of such a queuing system, the following statuses can be differentiated [4]:

E_0 – no customers (system idle), all servicing channels idle,

E_1 – one customer in the system, one channel busy,

*E*2 – two customers in the system, two channels busy,

…

E_i – *i* customers in the system, *i* channels busy,

…

E_m – *m* customers in the system, *m* channels busy,

…

E_j – j customers in the system, m channels busy, $j – m$ customers in the queue,

…

E_N – N customers in the system, m channels busy, $N – m$ customers in the queue.

The system is transformed from status E_0 into status E_1 by the stream of customers with intensity $N\lambda$ (as any transport unit can arrive from among N units remaining outside the system). In turn, the system turns from status E_1 into E_2 due to stream $(N\text{-}1)\lambda$, as one customer is being serviced, while N-1 units remain outside the system, etc.

The transition from status E_1 to E_0 occurs with servicing intensity μ. In turn, the intensity of transition from status E_2 to E_1 occurs with intensity 2μ. Similarly, intensity of $i\mu$ characterises the transition from E_i to $E_{i\text{-}1}$, where $0 < i \le m - 1$, and intensity of $m\mu$ - transitions from E_{j+1} to E_j at $m - 1 \le j \le N - 1$.

The graph of statuses of the system marked according to notation by D. Kendall *M*/*M*/*m*/FIFO/*N*/*F*, namely with Markov processes related to both customers – *M*, as well as servicing – *M,* with *m* channels and FIFO servicing (in the order of arrival), and *N* customers operating in the closed cycle *F*, has been presented in Fig. 2.

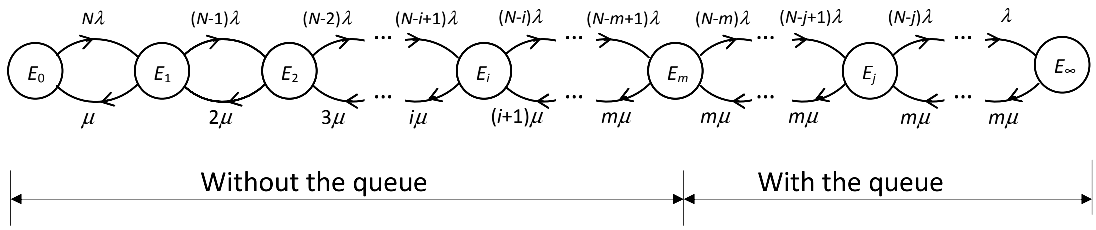

Figure 2: The graph of statuses of the M/M/m/FIFO/N/F system, acc. to [4]

When describing the dynamics of the system with the set of differential equations (according to the mnemonic rule, on the basis of the Chapman–Kolmogorov equation), and considering initial conditions and the normalising condition, a system of algebraic equations are obtained for the steady state, from which a formula is derived defining the probability p_i of having i customers in the system, as well as formulas for the characteristics specified below.

The probability of the service apparatus being idle amounts to:

$$p_o = \left(\sum_{i=0}^{m} \frac{N!}{i!(N-i)!} \rho^i + \sum_{k=m+1}^{N} \frac{N!}{m!(N-k)!m^{k-m}} \rho^k \right)^{-1} \tag{1}$$

Probability p_i and p_k of having i and k customers in the system amounts to [4]:

$$p_i = \frac{N!}{i!(N-i)!}\rho^i p_0, \quad i = 1, \ldots, m, \tag{2}$$

$$p_k = \frac{N!}{m!m^{k-m}(N-k)!}\rho^k p_0, \quad k = m+1, \ldots, N, \tag{3}$$

The case *I = 0* means that the service apparatus is idle, and there is no customer in the system, while in the case of $1 \le i \le m$, *i* customers are being serviced, while the queue status still equals 0. It is only in the case of $m+1 \le k \le N$ that *m* customers are being serviced, while *k – m* wait in the queue.

Average number of customers *q* waiting in the queue is calculated according to the following formula [4]:

$$q = \sum_{j=0}^{N-m} j p_{m+j} = \frac{N!}{m!} p_o \sum_{j=0}^{N-m} \frac{j}{m^j (N-m-j)} \rho^{m+j}. \tag{4}$$

3. THE QUEUEING MODEL FOR THE CASE OF ORDERS DIRECTLY AFTER UNLOADING

When analysing concrete mix supplies and its pumping at the building site, apart from the organisation where *N* concrete mixers circulate in a closed cycle, other solutions can be applied with "ordering deliveries directly after unloading". In order to describe the organisation with "ordering deliveries…", one can apply the *M/M/N/-/N* queuing system.

Let us assume that we have *N* transport units (vehicle concrete mixers), while the time of mix loading and transport to the site, as well as unloading/pumping are independent random variables with exponential distributions, with average values of $\frac{1}{\lambda}$ and $\frac{1}{\mu}$, respectively, whereas $\rho = \frac{\lambda}{\mu}$, $\rho < 1$.

$p_j(t)$ is the probability of a situation where at the time *t*, there is a „surplus" of *i* concrete mixers ahead of the pump. Directly after unloading each delivery, another delivery is ordered, with immediate loading of another concrete mixer at the production plant and its transport to the site. Therefore, the sum of transport units at the site and ordered equals to their maximum number *N.*

When analysing the graph of transitions presenting evolution of the number of concrete mixers at the site, three characteristic cases can be observed; Fig. 3, [4]:

– no surplus, 0 transport units to be unloaded, *i* = 0,

– the number of units ahead of the pump amounts to *i*, *i* = 1, …, *N* – 1,

– the number of units amounts to *N*, *i* = *N*.

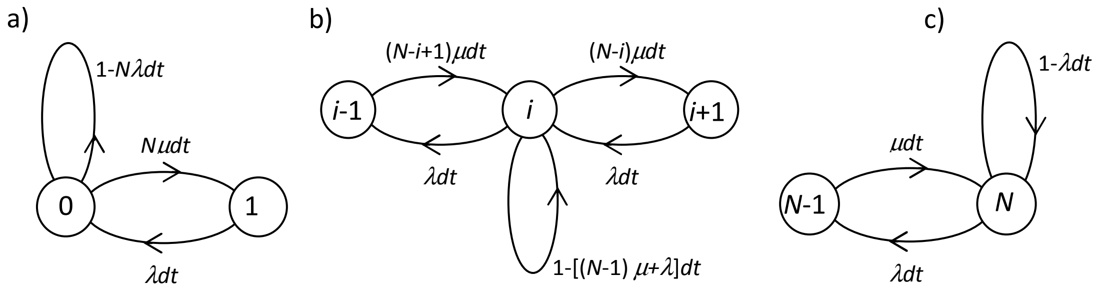

Figure 3: Characteristics of time: a – dla i = 0, b – dla i = 1, …, N – 1, c – dla i = N

If the number of ongoing orders substitutes the surplus volume, the order of status numbering is reversed, and we receive the *M/M/N/-/N* model, namely for *m* = *N,* [4].

In such a case, in the steady state, probability of service apparatus idle state amounts to the following:

$$p_o = \lim_{t\to\infty} p_o(t) = \frac{\dfrac{\rho^N}{N!}}{\sum\limits_{j=0}^{N} \dfrac{\rho^j}{j!}}. \tag{5}$$

The average number of concrete mixers unloaded within a time unit amounts to:

$$Q = \lambda(1 - p_0), \tag{6}$$

while the average number of transport units at the site amounts to:

$$\overline{n} = \sum_{j=1}^{N} jp_j, \tag{7}$$

whereas the average number of orders (loading commencements) in a time unit can be determined on the basis of the following relation:

$$\mu(N - \overline{n}) = \lambda(1 - p_o)\ . \tag{8}$$

4. GUARANTEED DELIVERY/PUMPING TIME AND DIRECT COSTS

In the analysed systems *M/M/m/*FIFO*/N/F* and *M/M/N/-/N,* the operation of concrete mixers and the pump is interpreted with Markov processes referring to arrivals and servicing. Also, the exit process complies with exponential distribution:

$$f(t) = \lambda e^{-\lambda t}, \quad t \geq 0, \tag{9}$$

with the cumulative distribution function:

$$F(t) = 1 - e^{-\lambda t}, \quad t \geq 0. \tag{10}$$

After transformation and taking logs, the following is obtained:

$$\lambda t = \ln \frac{1}{1 - F(t)} \tag{11}$$

Value *t* – the longest duration of delivery/pumping τ_{dp} can be calculated after substitution: of the cumulative distribution function *F*(*t*) with the required probability level to be guaranteed to observe *t,* and of $\frac{1}{\lambda}$ with average number *Q* of concrete mixers unloaded by the pump at the site.

The most favourable number of transport units (*N*) for the concrete laying team with the pump can be determined by minimising the total of direct costs resulting from the operation of the servicing system, and additionally from the increase of unit cost of concrete mix with the increased time of the start of setting τ_{pw} (required to meet the terms of high guarantee).

The sum of direct costs of system operation and increased cost of the mix per one loading amounts to:

$$K_b = \frac{K_{bp} + \bar{n} K_b + k_m(t)}{Q}, \tag{12}$$

where, acc to [15]:

K_{bp} – cost of machine-hour of mix pump operation, K_{bp} = 229 PLN/h,

K_{bm} – cost of machine-hour of concrete mix rental, K_{bm} = 143 PLN/h,

$\bar{n}$ – average number of customers in the system, acc. to (7),

$k_m(t)$ – additional unit cost due to application of the mix with increased time of commenced setting [3], $t < \tau_{pw}$, $k_m(0 < t \leq 3) = 0$, $k_m(3 < t \leq 12) =$ (8.89 PLN per each commenced 0.5 hour), *Q* – average number of unloading procedures during one hour of team operation, acc. to (6).

5. EXEMPLARY RESULTS OF CALCULATIONS ACCORDING TO *M*/*M*/*N*/-/*N* AND *M*/*M*/1/FIFO/*N*/*F* MODELS

The example uses the data from empirical measurements upon concrete laying for the span of trestle at the crossing of Wielicka and Powstańców Śląskich i Wielkopolskich Streets in Krakow, where 1057 m^3 concrete mix was built-in, delivered in concrete mixers with nominal capacity of 8 m^3 (via streets in the city) from the plant situated 7.5 km away from the site. The following average time values were determined:

– loading at the concrete plant and transport of the mix to the site (31 minutes 53 seconds), $\frac{1}{\lambda} = 0{,}531389$ h,

– "circulation" (according to section 2, including the passage of the vehicle for the mix, its loading and return at the site; 50 minutes 20 seconds) $\frac{1}{\lambda^*} = 0{,}838885$ h,

– pumping of the mix from one delivery (16 minutes 44 seconds), $\frac{1}{\mu} = 0{,}278833$ h.

A Results of calculations in the case of deliveries directly after completion of unloading

For the data as above: λ = 3.586372, μ = 1.881861, ρ = 1.905758, and for *N* = 1, …, 10, when applying the *M*/*M*/*N*/-/*N* model, according to formulas (5 ÷ 7), probability was calculated of idleness of the service apparatus p_0, average numbers of transport units at the site $\overline{n}$ and average numbers of concrete mixers unloaded in time unit *Q* have been presented in Fig. 4. According to (11, 12), average values were calculated for delivery/pumping times $\overline{\tau}_{dp}$, as well as the greatest (limit) durations $\tau_{dp,90\%}$, $\tau_{dp,95\%}$, $\tau_{dp,99\%}$ and direct costs $K_{b,90\%}$, $K_{b,95\%}$, $K_{b,99\%}$, which are not exceeded with the probability of 90%, 95%, 99%, respectively.

When analysing the calculation results, the lowest direct costs (considering the cost related to increase in the time of cement setting commencement) are recorded for the solution using three concrete mixers. In this case, the cost is minimal and amounts to $K_{b,95\%}$ = 152.31 PLN per one delivery/unloading. This is at 95% guarantee of not exceeding the duration of delivery/pumping amounting to $\tau_{dp,95\%}$ = 2.06 hours (counting from cement mixing with water at the concrete plant until the end of pumping the mix at the site). Probability of pump idleness in such a case amounts to p_o = 0.1963, while the average length of the queue *q* = 0.66.

In the case of using a greater number of transport units, the probability of pump idleness intensely decreases, and e.g. at *N* = 4 transport units, the probability of pump idleness amounts to p_0 = 0.085. The application of 4 concrete mixers, however, is related to the prolongation of concrete mixer waiting for unloading on average by 0.17 h, and to the unfavourable share of long servicing, e.g. greater than $\tau_{dp,95\%}$ = 2.59 h, which then occur with the probability of 5%.

Therefore, in the existing conditions, the most favourable solution is the one using *N* = 3 concrete mixers.

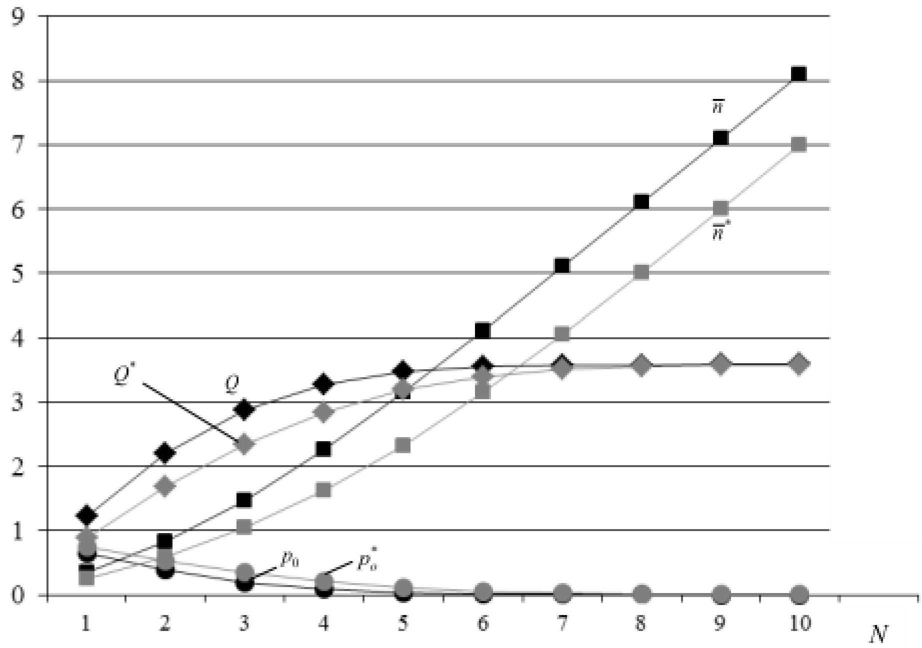

Figure 4: Variability: p_0, p_o^* – of probabilities of pump idleness, $\overline{n}$, $\overline{n}^*$ – average numbers of transport units at the site, Q, Q* – average numbers of concrete mixers unloaded during a time unit, respectively according to models M/M/N/-/N and M/M/1/FIFO/N/F, depending on the number N of transport units (own study)

B. Results with the assumption of units' operation in the closed circuit

When executing large monoliths, solutions are often applied where *N* concrete mixers operate in a closed circuit, namely immediately after unloading, each unit drives to the concrete plant, where the mix is loaded, and then returns to the site. It is an operational scheme that can be described with typical queuing system *M*/*M*/1/FIFO/*N*/*F*. In such a case, for the data as above λ^* = 1.192058, μ^* = 3.586372, ρ^* = 0.332385; the characteristics of the model calculated according to formulas (1 ÷ 4) have been presented in Fig. 4.

C. Calculated acc. to *M*/*M*/*N*/-/*N* and *M*/*M*/1/FIFO/*N*/*F*, particular model characteristics reveal very clear differences, mainly at small *N* values. In the case of the most favourable solution with the application of the *M*/*M*/*N*/-/*N* model (namely with delivery ordering directly after unloading) at *N* = 3 concrete mixers, efficiency *Q* features much greater values, with smaller values of both pump idleness probability p_0 and direct costs of system operation K_b, than the respective Q^*, p_0^*, and K_b^* values obtained in the model *M*/*M*/1/FIFO/*N*/*F*. Therefore, it is determined that in the case of performing large monoliths using concrete mixers, it is more favourable to apply the solution with deliveries directly after unloading, namely in the case of functioning according to the *M*/*M*/*N*/-/*N* model, rather than applying the organisation with *N* transport units operating (without control) in the closed cycle, according to the *M*/*M*/1/FIFO/*N*/*F* model.

6. CONCLUSION

The application of the Queuing Theory allows for analyses considering random variability of duration of particular processes, in particular modelling and analysing cooperation of the site units (e.g. brigades) with transport units, in order to determine the following:

- guaranteed durations of deliveries/pumping with the assumed probabilities of their observance, as necessary when planning concrete works execution, where portions of the mix built in must be connected still before cement starts setting.

On the basis of the studies of the team comprising the concrete laying brigade with a pump cooperating with concrete mixers (supplying the mix to the site, on municipal roads, from the concrete plant situated 7.5 km away), the following conclusions can be drawn:

- it is more favourable to implement the organisation with “deliveries directly after unloading” (where loading of the next transport unit at the plant begins immediately after completion of unloading of the concrete mixer at the site, after automatic sending of such information, e.g. using *RFID* system), rather than the organisation using *N* transport units circulating in the closed circuit (in the “self-regulating circuit”),
- in such a case, favourably, the efficiency of cooperating site and transport units is greater, while the probability of pump idleness is smaller, and the direct costs of building production are lower (as a result of shorter waiting time for unloading of vehicles with the mix at the site, and longer waiting time of unloaded concrete mixers at the plant).

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EFFECTIVENESS OF CONCRETE RUNWAYS CONSTRUCTION ON THE EVE OF AIR TRANSPORT DOMINATION

Andrzej Więckowski, PhD
Cracow University of Technology, Krakow, Poland, andrzej@ztob.wil.pk.edu.pl

Alicja Sznurawa
3rd degree student at Cracow University of Technology, Krakow, Poland, alisznurawa@gmail.com

Abstract

Air transport is nowadays one of the frequently chosen mean of transport for long distance trips. People tend to choose air transport over the railway and road transport. Thus airports have to be modernised and expanded. The aim of the paper is to evaluate the time and cost efficiency of constructing concrete runways and find optimal solutions. It requires an analysis of labour, materials and equipment.

The analysis was carried out for a design of a 3600-meter runway with set location considerations (Katowice-Pyrzowice airport). Reinforced and post-tensioned concrete runways have been compared. Runways design respected national (PN-EN) and ICAO regulations. National standards were applied while calculating the costs. They have been adjusted to the construction site and to the requirements of applied technology. All cost estimates were obtained from local suppliers/contractors. Moreover, the estimation of profits and other costs were analysed using statistical data. Time schedules were prepared for the runways using network analysis. They were based on seven days a week, twenty-four hours a day work. It was assumed that work units were optimised.

The following results have been obtained: cost calculation for post-tensioned runway was about 20 million PLN lower than for reinforced runway, which is 17% of the total cost. Duration of construction of post-tensioned runway was estimated to require 10 months whereas reinforced takes a little less time (assuming favourable meteorological conditions).

Concluding, in this case constructing post-tensioned runway is less expensive, however it require accuracy of realisation due to tendons placing and tensioning. The difference between runways cost is caused by much higher volume of concrete in reinforced pavement (20 cm thicker slab) Although post-tensioned runway cost is lower, the duration of its erection is slightly shorter. It is due to more complex realization of post-tensioned pavement.

Keywords: air pavement, construction management, cost estimation, runways.

1. INTRODUCTION

Civilizational development systematically changes the needs of the society, particularly as regards transport. One can observe a tendency that people want to travel increasingly quicker and cheaper. The emergence of “cheap airlines” on the market has evoked significant demand for their services. In most countries, significant growth in the number of passengers and cargo is observed, Fig. 1. As a result, also the number of airline operations increases. In Poland, e.g. at the Katowice-Pyrzowice airport, in the period from 1996 to 2012, the number of operations increased over eight times, Fig. 2. Such a high demand for services and, therefore, the need to increase the number of operations, have caused the need for many modernisations, extensions and construction of new airports.

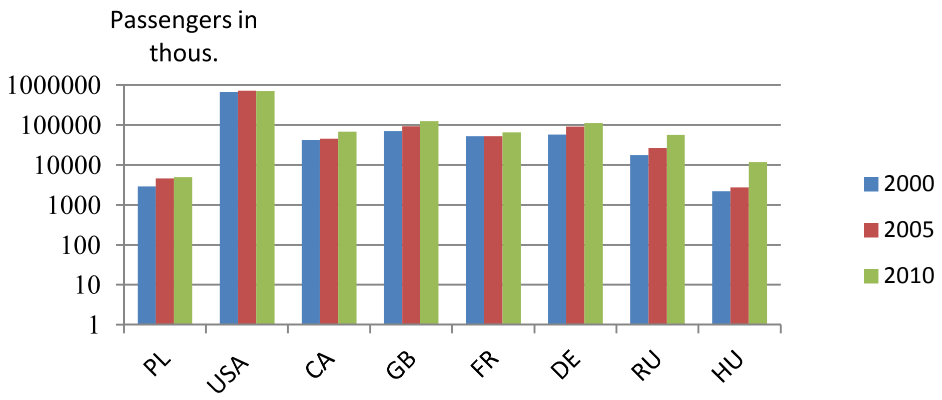

Figure 1: Transport of passengers, [based on 7].

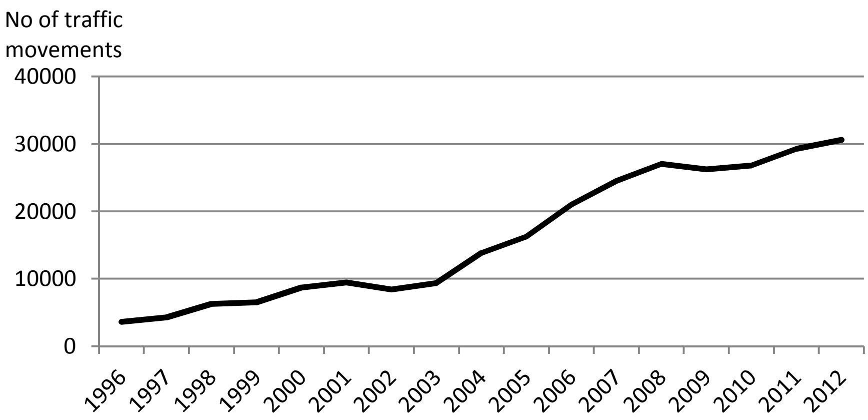

Figure 2: Airline operations at the Katowice-Pyrzowice airport in the years 1996 - 2012, [10].

Among the presently modernised airports, there is the Katowice-Pyrzowice airport (KTW), where a new runway is to be built. In the majority of literature items, as in [5], it is stated that prestressed structures can be much more expensive than other concrete structures. The application of prestressed structures allows for increasing the length of elements between joints, reducing their thickness, or for increasing permissible load without changing the geometry of the structure. In such a case, as compared to reinforced concrete structures, more precise execution is required, principally due to the need for prestressing and the occurrence of major actual forces in the structure. Prestressed pavements have been applied for airport construction since 1946 [4], yet presently they are rarely performed, giving way to reinforced or non-reinforced dowelled concrete structures. Below, at the example of modernisation of the Katowice-Pyrzowice airport, the effectiveness of solutions, as well as the runway construction cycle have been analysed in two variants, namely considering prestressed structure and dowelled structure.

2. TYPES OF RUNWAYS

Runways constitute the fundamental parts of airports. They can have following structures of pavements: of non-reinforced concrete, of reinforced concrete, of prestressed concrete, asphalt, and grass.

In the early period of aviation, runways usually had grass surface. The only requirement was the appropriately flat land and length adjusted to aircraft landing there. First airplanes could also land on meadows, agricultural fields, and other even surfaces.

The application of jet engines, however, revolutionised the technology of runway construction. Such engines, with significant forces of gas ejection, tore off parts of grass together with soil. Soil particles permeated into turbines of the engines and destroyed structural elements, causing their accelerated wear. The problem forced constructors to make runways with rigid pavements. At first, these were runways made of ordinary concrete. They were, however, characterised with high failure rate, as they tended to spall, and its pieces, similarly as soil particles previously, tended to destroy engines [5]. This accelerated further development of runway structures. Runways were improved in various manners. Developments included concrete runways with joints, runways covered with a layer of asphalt, runways of asphalt, and prestressed runways. Furthermore, continuous increase in aircraft weight (with culmination upon the emergence of the giant Boeing 747-400 with maximum vertical ground load at static totalling 414,130 kg) forced engineering of reinforced runways, particularly by increasing their thickness and bearing strength of sub base course.

The volumes of concrete and steel built into runways are currently very large. Reduced consumption of such materials rendered possible by the application of prestressed slab pavements, which are much thinner (by approximately 50%) than other concrete slabs. The first runway with prestressed structure was made at the Orly airport near Paris in 1946. It featured slabs with dimensions 60 m x 420 m [4]. Another prestressed runway was built eight years later, at the Maison-Blanche airport in Algeria. This was a prestressed runway with dimensions of 60 x 2,430 m. It involved bidirectional prestressing with 12-tendons strands with spacing of 1.75 m [5].

3. SELECTED ASSUMPTIONS AND ELEMENTS OF THE STRUCTURAL CHARACTERISTICS OF THE RUNWAY

Runway was designed in the 4E category, with the length of 3,600 m and width of 45 m. Category 4E means the width of the runway with sideways of 60 m. The new runway was located 200 m to the east from the existing runway. The investment required the performance of a costly operation of transferring rare flora into other areas.

Figure 3: Satellite photograph o Katowice-Pyrzowice airport with new runway, [11].

For the purposes of the studies, a structural design of the newly built runway at the Katowice-Pyrzowice airport was prepared, [10], using engineering assumptions according to [2] (the design did not include taxiways; it proved impossible to obtain the original execution design from the investor). The assumptions included load capacity of the runway fit for Boeing 747-400 JumboJet, with maximum vertical ground load at static amounting to 414,130 kg [1]. The runway was designed with concrete pavement, in two variants, with reinforced and dowelled structure, and as a prestressed structure.

Thickness of prestressed slab amounts to 25 cm. The runway was divided into 30 slabs, of three types (2 slab of type I, 6 slabs of type II, and 22 slabs of type III). Type I includes slabs with dimensions of 119 m x 45 m and maximum load capacity. Type II includes slabs with dimensions of 118 m x 45 m and also maximum load capacity. Type III includes slabs with dimensions of 118 m x 45 m and load capacity reduced by 40**%**. Between the prestressed slabs, there are jacking gaps with the width of 2 metres. The gaps allow for post-tensioning, and as a target, joints compensating for elements' expandability will be made on their edges. Sub base course of the runway is set 1.20 m below the land surface (namely 20 cm below the freezing zone level; in this case 1.00 m for zone II); Fig. 4

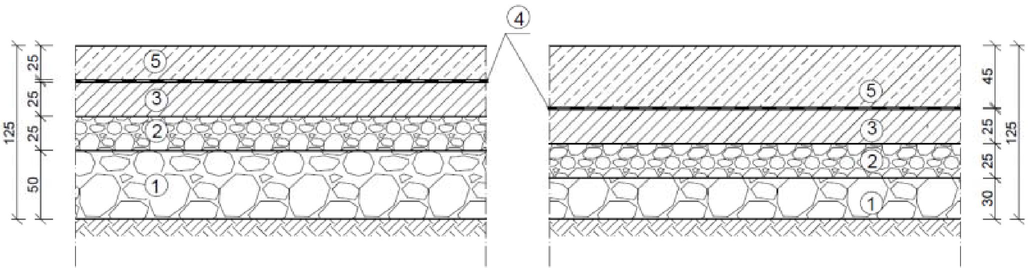

Figure 4: Fragments of runway cross-sections in two structural variants, where: 1 – crushed rock, 2 – sand-gravel mix, 3 – lean concrete course, 4 – slip sheets layer [own study]

The pavement slab is designed of concrete with compressive strength of C45/55, flexural strength F6,5, freeze resistance F150 and absorbability below 5%. Exposure of XF4 has been adopted. Covers amount to 60 mm for surfaces adjacent to external environment, and 30 mm for surfaces on the side of sub base concrete. The structure comprises prestressed concrete slabs with thickness of 25 cm. Tendons of 7ɸ5 mm in HDPE jackets have been applied (fpk = 1860 MPa) grouped by four strands laid in both directions. The tendons have been placed on supports of ɸ 6 rods with spacing not greater than 100 cm. The slab features circumferential reinforcement of rods ɸ 12, of RB500W steel, with spacing of 25 cm and spacer bars ɸ8 with spacing of 45 cm. Dowelling of slab edges has been applied with ɸ20 dowels of 90 cm length, placed between anchorages of tendons, with spacing from 30 cm to 50 cm, as presented in structural drawings.

Pavement slab of the dowelled runway is 45 cm thick, divided into sections with dimensions of 9 m x 9 m, and requires additional reinforcement. It is made on sub base course with 75 cm thickness, with layers according to Fig… , on slip sheets layer made of bituminous compound. According to [5], reinforcement of the section has been assumed with two reinforcement meshes: bottom, of ɸ16 rods every 20 cm longwise, and every 25 cm transverse, and top of ɸ12 rods every 25 cm, bent at the edges. Concrete as for prestressed slab has been applied.

4. ELEMENTS OF TECHNOLOGY AND WORK ORGANISATION

The intensity of traffic of various lorries (with total weight up to 40 tonnes) is very high during the construction, and on average amounts to 2.26 lorries per minute. Hence, on both sides of the runway constructed, temporary roads have been designed with the width of 6 m each, with extensions for pump stabilisation for the time of mix pumping. After removal of the vegetable earth layer, on the compressed sand mix levelled with cross-fall of 1% and thickness of 10 cm, roads and extensions were made of reinforced-concrete slabs with dimensions of 300 cm x 300 cm x 15 cm.

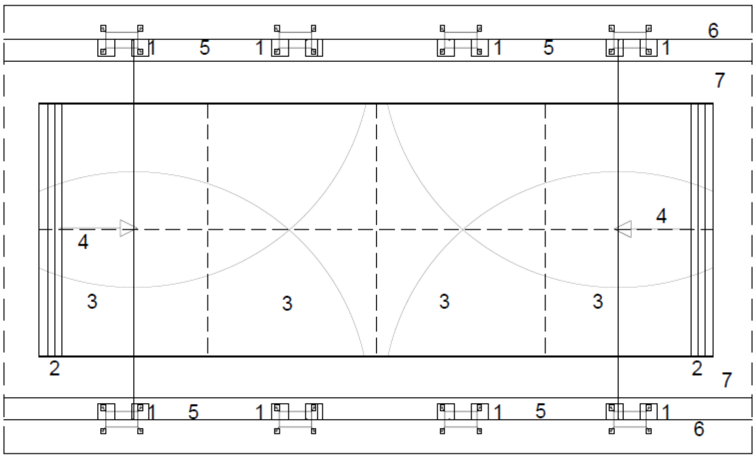

Figure 5: Concrete mixture pumping plan: 1) concrete pump, 2) vibrating screed, 3) concrete pump radius, 4) direction of works, 5) stopping area, 6) temporary road, 7) lean concrete course [own study].

On the basis of efficiency analyses, feeding of concrete mix has been planned with four mobile pumps. The pumps are located symmetrically against the centre of horizontal projection of the element built, Fig. 5 . First, the pumps are set on workstations. Each two pumps begin mix pumping, starting from the edges of opposite sides. Two pumps opposite one another, on both sides of the slab, lay concrete mix within the same belt, from edges to the centre, coming closer to one another until they meet. After the first belt is completed (on the entire width of the slab), they commence and execute the following belts, from the edges of the slab (adjusting the width of the belts to the efficiency of the concrete pumping team, [8]). Therefore, the works approximate one another from opposite sides until they meet.

Naturally, while pumping concrete, for each in-built mix portion k, k = 1,2,..,n, the following conditions must be met (time intervals refer to points at the numerical axis in a one-dimensional coordinate system):

$$t_w^k < t_w^{k+1},$$

$$t_w^{k+1} < t_{pw}^k,\ t_w^{k+1} < t_{pw}^{k+1}, \tag{1.1}$$

$$k = 1,2,..,n\text{-}1,$$

where:

t_w^k, t_w^{k+1} - completion of building in the mix portion *k* and the next portion *k*+1,

t_w^k, t_w^{k+1} - commencement of cement setting in portion *k* and in the next portion k+1.

The application of pumps with horizontal reach of 36 m. The pumps are stabilised on supports placed on extensions of temporary roads, made of concrete slabs. The mix is compressed with poker vibrators, levelled and panned with a vibrating screed, with a platform for the staff, with modular length. The screed features a combustion engine that drives the shaft with deadweights placed off-centre. The screed is made of modular truss with triangular cross-section with dimensions of 100 cm x 200 cm, with total length of 46 m. It serves for finishing, compression, levelling and smoothing the surface of the concrete mix pavement. From the platform of vibrating screed, initial compression of the mix is performed using poker vibrators. The screed moves on the rails placed along the longer edges of the slab.

Initial prestressing begins after concrete has achieved compressive strength equal to 12 MPa in sample cubes or 10 MPa in sample cylinders (according to EN-206/2000). In practice, initial prestressing takes place after 24 hours from completion of concrete pumping. First, tendons are compressed lengthwise, and then crosswise. Final prestressing is performed after concrete has achieved compressive strength equal to 24 MPa in sample cubes or 20 MPa in sample cylinders. After the end of tensioning, anchorages must be secured, dowels installed, and then jacking gaps must be reinforced and filled with concrete. Runway pavement is finished on the surface by grooving, with the application of cutters with diamond blades.

Reinforced slabs are made as monolithic, with dimensions of 45 x 45 m. Every 45 m, there is an expansion joint of 35 mm thickness, filled with compressible material. Concrete pumping has been planned just as for compressed slabs, with four pumps featuring reaches of 35 m, but the mix is pumped in two layers, [9]. Two pumps feed the mix at the same time, performing bottom layer of 25 cm thickness. The layer is compressed manually with poker vibrators. Next, two further pumps perform top layer of 20 cm thickness. The mix is then compressed manually with poker vibrators, and on the surface with a vibrating screed, Which at the same time levels the surface. The second layer must be made still before the bottom layer starts setting, according to the conditions [9].

Next, joints must be performed, dividing the slab into a set of squares of 9 x 9 m. Cuts are made in two phases. First time, after concrete has achieved compressive strength of 10 MPa. In practice, this is usually after 8 h to 12 h. The process of first cutting must be completed before 24 h from the end of concrete pumping. The first cut, made with concrete cutting blades, at the depth of 1/3 to 1/4 of slab thickness. The cuts are about 4.0 mm wide. After concrete has achieved compressive strength of 24 MPa, the joints are widened to the designed width. After cuts have been made, the slots must be carefully cleared and filled with pourable sealing compound. Such runway pavement must be finished on the surface by grooving with concrete cutters.

5. CONSTRUCTION CYCLES OF STRUCTURAL VARIANTS

When planning the organisation of teams executing particular works, in the context of methods and technological order of works, 8-hour shifts have been planned with 5-day working week, from Monday to Friday inclusive, for all brigades except for prestressing teams. Such teams perform prestressing usually one to eight days after concrete pouring. Hence they have to work on Saturdays, and sometimes also on Sundays. No additional limitations have been considered, as may be imposed by the airport.

The volume of works is very large. Hence, the brigades usually have double numbers of the same types of the equipment. In turn, when concrete pumping, as many as four pumps must operate simultaneously, feeding concrete mix supplied by 42 truck concrete mixers from concrete-mixing plant for the purposes of the site, and from two standby concrete-mixing plants.

The works have been planned according to the uniform work method. Five operating plots have been applied, with section lengths of 600 m (each plot covers the area of 5 prestressed slabs with jacking gaps). In the plans for executing the whole investment, a uniform, three-week rhythm of work has been adopted (with five business days per week). Work completion time can be calculated according to the following relation [8]:

$$t^D = r(m + n - 1),$$

where:

r – rhythm duration, r = 3 weeks,

m – number of work processes executed, m = 9,

n – number of plots, n = 6.

After substitution to formula () and calculation, work duration amounts to:

t^D = 42 weeks (namely 294 calendar days).

In the case of runway construction according to variant II, there is no prestressing process, hence m = 9. Then, according to formula (), work duration is shorter just by r = 3 weeks, namely by 7% as compared to construction cycle time applicable for runway with prestressed structure.

According to the guidelines, before commencement of construction works, natural habitats present on the area of the planned runway must be removed and relocated into other places. The performance of such works prolongs the runway construction cycle by eight weeks (as only after completion and evaluation of works can the runway construction begin). Hence, total investment completion time tC = 50 weeks, namely about one year. In the Polish climatic conditions, it would be most favourable to commence the works in the second half of September, so as to replant the bushes in autumn, while in early spring, immediately after defrosting of soil, to start preparation of temporary roads for the site, and if the temperatures permit it, to carry out earth works and other works. Concrete-related works take 21 weeks (about 5 months). Therefore, they will be executed in the following seasons:

spring, summer and autumn. Therefore, in the case of high air temperatures during the day, concrete pumping must be performed at night, when the temperatures are lower.

6. COST ANALYSIS

Cost estimate prices have been determined for two variants of runway performance. Labour cost – R has been determined for unit labour rate of 5€/h, while the cost of materials - M and operation of the equipment – S have been determined according to [6] and on the basis of prices of local suppliers. Cost estimate prices, CC – include indirect costs (Kp=0.65*(R+S)) and profit (Z=0.1*(R+S+Kp)); as well as VAT PV = wV (R + M + S + Kp + Kz + Z).

A. Total cost estimate price, VAT inclusive, for the performance of runway with pavement with prestressed structure, namely according to variant I, amounts to 35.3 M €, Fig. 5. In turn, the performance of the runway with dowelled reinforced concrete structure, namely according to variant II, is valuated at 41.7 M €. The large difference in prices, equal to 6.4 M €, resuts from the change of material disbursements, principally due to material consumption of dowelled pavement.

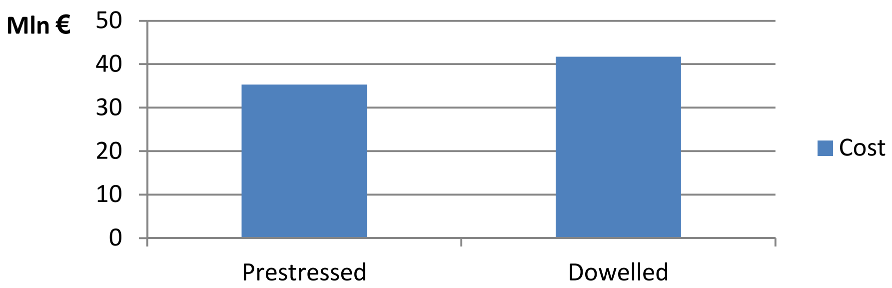

Figure 6: Total cost estimate prices (VAT inclusive) for performance of the runway according to two structural variants [own study]

B. Prices (VAT inclusive) for performance of sub base course and base course of the runway have been presented in Fig. . The price of crushed rock and sand-gravel mix layers in the case of pavement with dowelled structure amounts to 10.7 M €, and is lower by 2.4 M € than the price of such layers with prestressed structure. This results from different thickness of such sub base course parts. In turn, over three times greater price difference than in the case of layers of crushed rock and gravel in sub base courses occurs between variants I and II of concrete sub base and concrete base course (with standard and prestressing reinforcement, applied in particular variants). In this case, the cost estimate price of concrete layers, sub base and pavement of the runway with prestressed structure amounts to 20.6 M €, and is lower by 8.8 M € than the price of such layers with dowelled structure. Such a large difference is principally due to concrete layer of pavement of the runway with traditional structure, which is by 20 cm thicker than the concrete layer of pavement with prestressed structure.

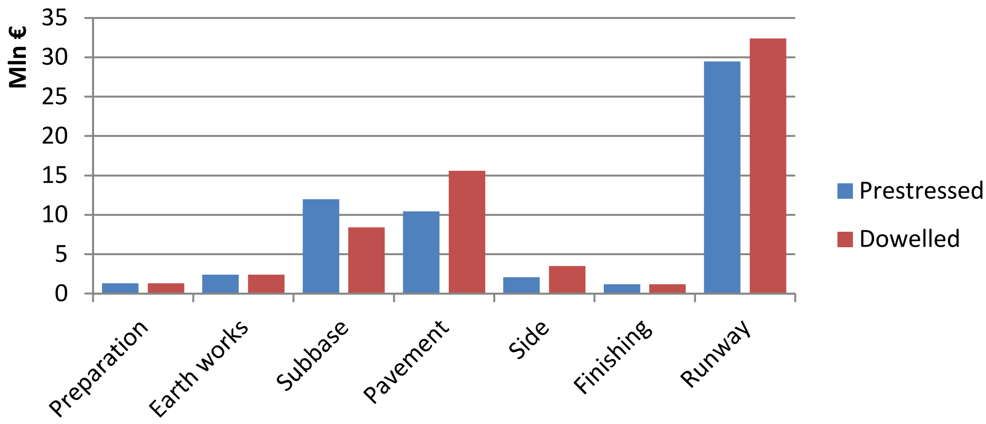

Figure 7: Structure of work price components. Total disbursements [own study]

C. Disbursements on labour *R*, materials *M* and equipment operation *S*, Fig. , in the variants significantly differ. Labour consumption of the solution with prestressed runway amounts to 465,000 working hours and is greater by 20,000 working hours than in the case of traditional concrete structure. Furthermore, greater precision is required, as well as strict timeliness of all works related to prestressing.

In turn, steel consumption is much lower, by 600 tonnes, while in the case of concrete mix by 43,000 m^3 as compared to dowelled structure, because for prestressed load-bearing structure it amounts to 3,500 tonnes and 110,000 m^3, respectively. Also, equipment operation is lesser, by 11,000 machine-hours, including the pumps, by 2,000 machine-hours, than in the case of prestressed structure.

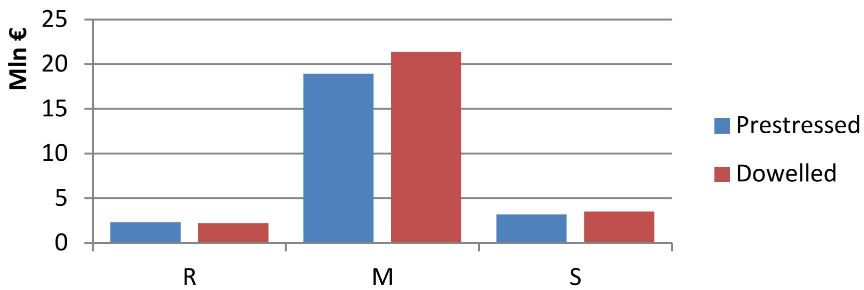

Figure 8: Disbursements in the analysed variants of runway construction, R – labour, M – materials, S – equipment operation [own study]

7. CONCLUSIONS

At present, the clearly increasing global demand for civil aviation services, there is a need for many repairs and modernisations, as well as construction of new runways for airplanes. On the basis of calculations performed for the newly built runway at the Katowice-Pyrzowice airport with prestressed structure, as compared to solutions with dowelled reinforced concrete pavement, the following conclusions can be drawn:

1.) Fundamental benefits from prestressing include:

– about double reduction of the thickness of load-bearing structure and reduced consumption of steel by 14% (whereas in this case this is principally extra-fine steel for prestressing),

– greater resistance to overload and cracking of the structure,

– operational profits resulting from greater pavement durability (without micro-cracks) and smaller number and length of joints.

2) Investment cycle is slightly longer, only by 7%, yet execution of the processes requires greater precision of works and observance of work schedule (in particular in the case of prestressing works).

3) Cost estimate price of runway performance is lower by 16,9%, principally due to lower cost of concrete layers by 78%.

4) Disbursements on equipment operation are lower by 10%, while particular difference is observed in the case of much lower volume of in-built concrete mix by 43,000 m^3 (namely the volume corresponding to capacity of 5,500 truck concrete mixers), whereas labour consumption of the works is greater by 4% (which includes specialist prestressing).

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KNOWLEDGE MANAGEMENT IN CONSTRUCTION: SOUTH AFRICAN CONTRACTORS' PERCEPTIONS

W Wiegand
Nelson Mandela Metropolitan University, Port Elizabeth, South Africa,

J. Smallwood
Nelson Mandela Metropolitan University, Port Elizabeth, South Africa,
john.smallwood@nmmu.ac.za

Abstract

Knowledge management (KM) in the construction industry is relatively unknown and therefore is rarely adopted on a notable scale. With meticulous recording of previously incurred errors / mistakes, best practices, and the transfer of experiential knowledge, the performance of the construction industry can be greatly improved.

The areas in need of improvement are preventing the replication of errors / mistakes, employee personal knowledge, and the achievement of performance and standards set, and client satisfaction. KM can be utilised as a medium to increase employees' personal knowledge as well as creating a better performing organisation and competitive edge.

Given the aforementioned, a descriptive survey was conducted among general contractor (GC) members of the East Cape Master Builders Association (ECMBA). The salient findings include: KM is generally not practiced to a great extent in South Africa; KM is merely a tool utilised by the workforce; there is a lack of belief in the KM process by organisational staff; employees are reluctant to share their experiential knowledge, even with individuals within the firm, and KM has a positive effect on performance and client satisfaction.

In today's competitive construction industry, KM is essential in terms of a firm's sustainability and future profitability. KM has to be embraced by all employees of a firm for its true potential to be achieved.

Keywords: Knowledge management, knowledge sharing, knowledge transfer, explicit knowledge, tacit knowledge.

1. INTRODUCTION

KM deals with the process by which knowledge is created, acquired, communicated, shared, applied, and effectively utilized and managed, in order to meet existing and emerging needs, to identify and exploit existing and acquired knowledge assets (Anumba & Ruikar, 2008).

KM has a profound effect on the creative / innovative side of an employee's mind, upon attaining knowledge of new innovations and, furthermore, being confronted by similar situations, the human mind will adjust and solve the problem specific to the problem at hand. Technology supports connectivity as most of the construction knowledge resides in people, not technology (Uwakweh, 2011).

As the global economy is ever-changing, it is crucial for construction organisations to adapt with it. Every year, the construction industry has become more and more competitive with organisations having to enter into contracts with uncharacteristically low profit margins. Furthermore, a minor aspect can induce the confidence of the clients of today, and having a strong KM culture on site can only increase client interest.

Given the aforementioned a study was conducted to address the following issues:

- Contractors replicate past errors / mistakes;
- Interns / new employees / existing employees do not develop at a rate possible if knowledge management were used to its full potential;
- Contractors do not improve performance;
- Contractors do not achieve the required standards, and
- Clients are dissatisfied with overall performance introduction.

2. REVIEW OF THE LITERATURE

2.1. Contractors replicate past errors / mistakes

Robeiro & Ferreira (2010) determined that KM offers an extensive possibility for application in construction projects, and Yu-Cheng *et al.* (2006) point out that the application and reuse of previously finished projects for similar projects in the future is the core concern of KM in the project construction phase. Yu-Cheng *et al.* (2006) determined that sharing experience and knowledge leads to prompt solutions in the future i.e. problems are not repeatedly solved. Reusing information and knowledge diminishes the need to refer explicitly to past projects, reduces the time and cost of solving problems, and improves the quality of solutions during the construction phase of a construction project (Yu-Cheng *et al.*, 2006). Therefore, it is important for organisations to be able to recognise and acquire new knowledge, best practice, and knowledge gap opportunities (Yasin & Egbu, 2011).

2.2 Development of interns / new employees / existing employees

A KM framework can increase the ability of a site manager to learn from his / her environment and to incorporate knowledge into site management practices (Uwakweh, 2011). A project will almost always lose time and money while controlled by new or developing employees; this is due to the shear lack of knowledge of how the real world of construction operates. The experienced employees within an organisation, when possible, need to guide / mentor these new or developing employees so they learn what to do and how to react in different situations.

Akehurst *et al.* (2011) point out that new knowledge is created through new aspects of a physical, technical, and social nature, and Kamara *et al.* (2002) describe the key process of knowledge transfer or acquisition as involving employees in different situations or activities. Therefore, KM has major potential to raise an individual's personal knowledge as well as influence an organisation's competitiveness.

Yasin & Egbu (2011) found that knowledge continually evolves and from this Mohd *et al.* (2011) determined that this attained knowledge must be transferred at its maximum potential for the organisation to reap notable organisational advantages. Processing an individual's personal knowledge into an organisation asset is an important step in the knowledge sharing process, in terms of a competitive advantage (Mohd *et al.*, 2011).

Without a proactive KM strategy in place, an organisation will not be able to reach its full KM potential (Kamara *et al.*, 2002). It is more difficult to transfer tacit knowledge, however it may be transferred through sound communication between individuals with a shared understanding (Sharpe, 2001). Information computing technology can intensify the teamwork between individuals and groups to produce network systems to support a knowledge flow (Ribeiro, 2009).

2.3 Contractors do not improve performance

Kamara *et al.* (2002) identify the need to cope with organisational changes with respect to high staff turnover and changing business practices. Construction adds challenges as it is transient, and entails the establishment of new teams upon commencement of projects. The constant adjusting and re-adjusting creates an atmosphere where it is difficult to work at peak performance.

A knowledge-based business is a knowledge intensive one; where organisations use their information capital to increasingly find new ways to add value to their existing business processes (Anumba & Ruikar, 2008. It involves a creative and innovative combination of existing knowledge capital with newly acquired or created knowledge, to maintain competitive advantage (Anumba & Ruikar, 2008). It is very easy for contractors to become trapped in a routine, in this case, never improving on their previous performances. This is where KM realises change in the industry as contractors are constantly made aware of new, more efficient techniques and procedures which will stream line work on projects.

A major challenge in knowledge utilisation is the way in which knowledge is leveraged in construction firms to improve project performance (Robeiro & Ferreira, 2010). Robinson *et al.* (2001: 1) identify the significant barriers as organisational culture, lack of standard work processes, and time constraints.

2.4 Contractors do not achieve the required standards

Knowledge of organizational statutory regulations, standards, and the management of the interfaces between different stages / components of a project is the start to achieving require client standards (Kamara *et al.*, 2002).

Aspects of an organisation such as time constraints, lack of adequate KM resources, lack of communication skills, and attitude of the staff have an impeding influence on standard attainment (Mohd *et al.*, 2011). Therefore, organisations often need to introduce specialised knowledge from different sources, which knowledge is then spread among individuals, teams, and units (Kumar & Ganesh, 2009).

2.5 Clients are dissatisfied with overall performance introduction

A range of seminal reports report on client dissatisfaction, *inter alia*, the 'Egan' (1998) report: "More than a third of major clients are dissatisfied with contractors' performance in keeping to the quoted price and to time, resolving defects, and delivering a final product of the required quality."

Construction organisations are generally not prepared to invest resources in developing new initiatives and innovations due to the resultant low profit margins (Robinson *et al.*, 2001). This failure to change and evolve with world trends advantages competitors, which in turn is not attractive to clients.

Uwakweh (2011) assures that there is much scope for making construction organisation more competitive through better KM processes. Evolving into a more competitive organisation indirectly increases client satisfaction as becoming a more competitive organisation means improved project delivery, which in turn increases client satisfaction.

3. RESEARCH METHODOLOGY AND SAMPLE STRATUM

The sample stratum consisted of 63 medium and large sized general contractor members of the East Cape Master Builders Association (ECMBA), which constitutes an employer association for, inter alia, building contractors based and or operating in the Eastern Cape

Province of the Republic of South Africa. 19 responses were received and included in the analysis of the data, which equates to a response rate of 30.6%.

The self-administered questionnaire delivered per e-mail, consisted of 7 sections, 25 questions, 19 of which were 5-point Likert scale type questions. Various methods were used to increase and optimise the response rate, *inter alia*, GCs were individually contacted per e-mail and in many cases telephonically; two months subsequent to the initial questionnaire e-mail, the questionnaire was posted to the remaining GCs who had yet to respond, and personal phone calls were made and ad-hoc meetings with certain GCs.

4. RESEARCH FINDINGS

The majority of the respondents (84.2%) have 15 years or more of construction related experience - 36.9% have '> 15 Years ≤ 25 Years' experience, 31.6% have '> 25 Years ≤ 35 Years', and 15.8% have '> 35 Years'. Therefore, it can be said that the majority of the respondents have substantial experience, which enhances the credibility of their responses.

Number of Years	**Response (%)**
≤ 5 Years	5.7
> 5 Years ≤ 15 Years	10.5
> 15 Years ≤ 25 Years	36.9
> 25 Years ≤ 35 Years	31.6
> 35 Years	15.8

Table 1: Respondents' experience in the construction industry

Table 2 indicates the extent to which site workers replicate past mistakes / errors on projects in response to the question 'On a scale of 1 (never) to 5 (repeatedly), how often do site workers replicate past mistakes / errors on projects?' Given that the MS of 3.32 is > 3.00, site worker mistakes / errors on projects can be deemed to re-occur. However, in terms of ranges given that the MS is > 2.60 ≤ 3.40 they can be deemed to re-occur between rarely to sometimes / sometimes. However, 3.32 is just below the lower limit of the next range > 3.40 ≤ 4.20 – between sometimes to often / often.

<table>
<tr><th colspan="7">Response (%)</th></tr>
<tr><th rowspan="2">Unsure</th><th colspan="5">Never ……………………………………………………………………………..Repeatedly</th><th rowspan="2">MS</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>0.0</td><td>0.0</td><td>15.8</td><td>47.4</td><td>26.3</td><td>10.5</td><td>3.32</td></tr>
</table>

Table 2: Incidence of site worker mistakes / errors on projects

Table 3 indicates the extent to which site management replicate past mistakes / errors on projects in response to the question 'On a scale of 1 (never) to 5 (repeatedly), how often does site management replicate past mistakes / errors on projects?' Given that the MS of 2.53 is ≤ 3.00, site management mistakes / errors on projects can be deemed to re-occur infrequently as opposed to frequently. However, in terms of ranges, given that the MS is > 1.80 ≤ 2.60, they can be deemed to re-occur between never to rarely / rarely. However, 2.53 is just below the lower limit of the next range > 2.60 ≤ 3.40 - rarely to sometimes / sometimes. It is notable that in terms of Tables 2 and 3, no respondents identified 'never'.

Response (%)						
Unsure	**Never ……………………………………………………………………Repeatedly**					**MS**
	1	2	3	4	5	
0.0	0.0	57.9	31.6	10.5	0.0	2.53

Table 3: Incidence of site management mistakes / errors on projects

Table 4 indicates the importance of improving performance relative to 11 project parameters through the implementation of KM procedures in response to the question 'On a scale of 1 (not) to 5 (very), how important is the reducing of past errors / mistakes in terms of the achievement of performance relative to the various project parameters?' It is notable that all 11 parameters have MSs > 3.00, which indicates that the implementation of KM procedures is deemed to be important as opposed to less than important. It is also notable that 7 of the 11 (63.6%) MSs are > 4.20 ≤ 5.00, which indicates that improving project parameters through the implementation of KM procedures is deemed to be between more than important to very important / very important.

Cost (MS = 4.79), productivity (MS = 4.68), quality (MS = 4.68), time (MS = 4.68), and client satisfaction predominate, followed by'H&S (Construction) and H&S (Public). It is notable that the traditional parameters of cost, quality, and time are ranked within the top four. The remaining 4 (36.4%) MSs are > 3.40 ≤ 4.20: developmental objectives; designer satisfaction; worker satisfaction, and environment.

Employee category	**Response (%)**						**MS**	**Rank**
	Unsure	**Not ………………………………………Very**						
		1	**2**	**3**	**4**	**5**		
Cost	0.0	0.0	0.0	5.3	10.5	84.2	4.79	1
Productivity	0.0	0.0	0.0	5.3	21.1	73.7	4.68	2=
Quality	0.0	0.0	0.0	5.3	21.1	73.7	4.68	2=
Time	0.0	0.0	0.0	5.3	21.1	73.7	4.68	2=
Client satisfaction	0.0	0.0	5.3	5.3	15.8	73.7	4.58	5
H&S (construction)	0.0	0.0	0.0	5.3	42.1	52.6	4.47	6
H&S (public)	0.0	0.0	0.0	10.5	36.8	52.6	4.42	7

Developmental objectives	0.0	0.0	0.0	36.8	26.3	36.8	4.00	8
Designer satisfaction	0.0	5.3	10.5	10.5	31.6	42.1	3.95	9
Worker satisfaction	0.0	0.0	0.0	42.1	31.6	26.3	3.84	10
Environment	0.0	0.0	10.5	47.4	21.1	21.1	3.53	11

Table 4: Importance of reducing of past errors / mistakes in terms of the achievement of performance relative to the various project parameters

In response to the question 'Does your organisation have procedures in place to prevent past errors / mistakes from being replicated?' , 68.4% of respondents indicated their organisations o have such procedures in place, 26.3% do not and 5.3% were unsure.

Table 5 indicates the importance of knowledge sharing among employees in respondents' organisations in response to the question 'On a scale of 1 (not) to 5 (very), how important is knowledge sharing among employees in your organisation?' Given that the MS > 3.00, in general knowledge sharing among employees is deemed important as opposed to not important. In terms of ranges, the MS is > 4.20 ≤ 5.00, which indicates knowledge sharing among employees is more than important to very / very important.

Response (%)						
Unsure	**Not…………………………………………………………Very**					**MS**
	1	2	3	4	5	
0.0	0.0	5.3	10.5	31.6	52.6	4.32

Table 5: Importance of knowledge sharing among employees in respondents' organisations

In response to the question 'Does your organisation quantify the cost of errors / mistakes?', 73.7% of respondents indicated their organisations do, and 26.3% do not.

Table 6 indicates the frequency explicit and tacit 'knowledge are transferred to the existing employees / new employees / graduate interns in respondents' organisations in response to the question 'On a scale of 1 (never) to 5 (daily), how frequently are the following types of knowledge transferred to existing employees / new employees / graduate interns (please note the definitions below the table)?'

The mean MS for explicit (2.90) is ≤ 3.00, and therefore the frequency is deemed infrequent as opposed to frequent, albeit it marginally so. The mean MS for tacit (3.53) is > 3.00 and therefore the frequency is deemed frequent as opposed to infrequent. It is notable that relative to all categories the 'tacit' MSs are greater than the 'explicit' MSs.

Employee category	**Response (%)**						**MS**	**Rank**
	Unsure	**Never**	**Monthly**	**Fort-nightly**	**Weekly**	**Daily**		
Explicit:								
Graduate interns	10.5	5.3	15.8	15.8	36.8	15.8	3.11	1
New employees	10.5	5.3	15.8	21.1	31.6	15.8	3.05	2
Existing employees	10.5	15.8	21.1	26.3	15.8	10.5	2.53	3
Mean							2.90	
Tacit:								
New employees	5.3	0.0	15.8	10.5	42.1	26.3	3.63	1
Graduate interns	10.5	0.0	10.5	10.5	52.6	15.8	3.42	2
Existing employees	5.3	10.5	15.8	15.8	31.6	21.1	3.21	3
Mean							3.42	

Table 6: Frequency of explicit and tacit knowledge transfer in respondents' organisations

Table 7 indicates the frequency graduate interns / new employees / existing employees share information / experiences that they have previously experienced in response to the question 'On a scale of 1 (never) to 5 (daily), how frequently do the graduate interns / new employees / existing employees share information / experiences that they have previously experienced?' All the MSs are ≤ 3.00, which indicates the frequency is deemed infrequent as opposed to frequent, albeit it marginally so in the case of 'existing employees' (MS = 2.95). The MSs for existing employees and new employees are > 2.60 ≤ 3.40, which indicates the frequency is deemed to be between monthly to fortnightly / fortnightly. The MS for graduate interns is > 1.80 ≤ 2.60, which indicates the frequency is deemed to be between never to monthly / monthly. It should be noted that the MS is 2.58, which is marginally below the lower limit of the upper range, namely 2.60.

Employee category	**Response (%)**						**MS**	**Rank**
	Unsure	**Never**	**Monthly**	**Fort-nightly**	**Weekly**	**Daily**		
Existing employees	10.5	10.5	15.8	26.3	10.5	26.3	2.95	1
New employees	10.5	10.5	15.8	26.3	26.3	10.5	2.79	2
Graduate interns	15.8	15.8	10.5	21.1	26.3	10.5	2.58	3

Table 7: Frequency of knowledge sharing in respondents' organisations

Table 8 indicates the extent to which respondents' organisations share best practice knowledge in response to the question 'On a scale of 1 (never) to 5 (daily), how frequently does your organisation share best practices?' Given that the MS of 3.16 is > 3.00, best practice knowledge is deemed to be shared frequently as opposed to infrequently, albeit marginally so. However, in terms of ranges, the MS is > 2.60 ≤ 3.40, which indicates the frequency is deemed to be between monthly to fortnightly / fortnightly. This is a notable as sharing best practice knowledge is logical.

Response (%)						
Unsure	**Never**	**Monthly**	**Fortnightly**	**Weekly**	**Daily**	**MS**
	1	2	3	4	5	
5.3	10.5	15.8	15.8	36.8	15.8	3.16

Table 8: Frequency respondents' organisations share best practice knowledge

Table 9 indicates the extent to which knowledge sharing improves performance relative to the standards, organisation / client expectations, procedures, and project specific specifications in response to the question 'On a scale of 1 (minor) to 5 (major), to what extent does knowledge sharing improve performance relative to the standards, organisation / client expectations, procedures, and project specific specifications?' Given that the MS of 4.32 is > 3.00 knowledge sharing is deemed to improve performance to a major as opposed to a minor extent. However, in terms of ranges, the MS is > 4.20 ≤ 5.00, which indicates the extent is deemed to be between a near major to major / major extent.

Response (%)						
Unsure	**Minor ……………………………………………………………………………Major**					**MS**
	1	2	3	4	5	
0.0	0.0	0.0	10.5	47.4	42.1	4.32

Table 9: Extent to which knowledge sharing improves performance

Response (%)						
Unsure	**Minor ……………………………………………………………………………Major**					**MS**
	1	2	3	4	5	
0.0	0.0	5.3	10.5	36.8	47.4	4.26

Table 10: The extent the implementation of knowledge management / sharing will improve client satisfaction

Table 10 indicates the extent the implementation of knowledge management / sharing will improve client satisfaction in response to the question 'On a scale of 1 (minor) to 5 (major), to what extent will the implementation of knowledge management / sharing improve client satisfaction?' Given that the MS of 4.26 is > 3.00, the implementation of knowledge management / sharing is deemed to improve client satisfaction. However, in terms of ranges, the MS is > 4.20 ≤ 5.00, which indicates the extent is deemed to be between a near major to major / major extent.

5. CONCLUSIONS

KM on site and within the organisation can improve site performance through the sharing and eventual transfer of knowledge from one individual to another, therefore an organisation conducting business with a KM plan in place, generally has a competitive edge over organisations who do not implement KM processes. This is reinforced by the finding that the general standard of an organisation's work can be drastically improved through the implementation of KM through the reduction of past mistakes / errors. However, there is a lack of KM culture within organisations in South Africa, and KM is generally not practiced to the extent as is in developed countries. This is based upon the incidence of site worker and site management replication of past mistakes / errors on projects. This is also further reinforced by the low frequency of explicit and tacit knowledge transfer, particularly among existing employees. Ultimately KM improves performance and client satisfaction.

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AN INVESTIGATION INTO THE CURRENT STATE OF FEMALE STUDENTS AND FACULTY IN CONSTRUCTION MANAGEMENT PROGRAMS ACROSS THE UNITED STATES

Catherine Yaris
East Carolina University, Greenville, United States, yarisc12@students.ecu.edu

Syed Ahmed
East Carolina University, Greenville, United States, ahmeds@ecu.edu

Stephanie Nielsen
East Carolina University, Greenville, United States, nielsens08@students.ecu.edu

Abstract

The objective of this study is to examine and evaluate low female enrollment and numbers of faculty members in construction management and comparable programs in the United States. The researchers strive to answer the questions– What are the barriers women face in a male dominated field of study? What are the reasons why females choose other fields of study? How can we attract females to our construction programs and increase the female population? What is the current population of women in the undergraduate construction programs across the United States?

The Associated Schools of Construction (ASC) website offers a region by region list of universities with construction management and comparable programs. Using this list, each university was researched to find data about students and faculty in every program.

Results show that women are severely underrepresented in every region in both faculty and student capacities. Of the 63 schools with student data, females made up only around 7% of the population. Female faculty members only made up about 16%.

In conclusion, resolution of this problem must start at the collegiate, high school, and sometimes even grade school level. Several variables influence what draw women to construction programs while others deter women from entering the field. It is important to focus on changing the culture of the entire construction industry to decrease the stereotypes and increase women and minority involvement. Thus, ongoing research is focused on not only identifying women in construction academia but also to recruit and retain more women to create a less gender segregated construction industry.

Keywords: female population, undergraduate, graduate, construction management, university.

1. INTRODUCTION

In every society, there are certain industries that are classified as male or female dominated. One such industry is construction. In fact, this industry is ranked third in female and minority underrepresentation behind mining and manufacturing (Charles & Grusky, 2004). Another way to classify the construction industry for women is as a non-traditional career field. Specifically, this refers to male role specifications and positions that women do not seek or do not achieve (Winkelman, 1999).

The construction industry is also faced with a lack of skilled workers (Committee on Maximizing, 2006). This problem could be resolved by seeking out females and minorities to become skilled workers. The single biggest reason women are not prevalent in the construction industry is culture. The construction culture is aggressive and viewed as male-dominated confirming the stereotype. Thus, in order to overcome these barriers the culture of the construction industry must be changed and this can start with in academia whether it is in universities or even at grade school ages (Fielden, Davidson, Gale, & Davey, 2000).

Universities are faced and have been with low female enrollment rates. It is important to identify strategies and characteristics that draw females to these programs. Due to these low enrollment rates, the jobs across industries and education are also faced with a low number of women participants. This paper focuses on the current state of females in construction management programs as both faculty and students across the United States. From here, a foundation be laid to help increase the number of successful female faculty and graduating students.

2. BACKGROUND

2.1. Female Students

Overcoming the male image is a challenge that will continue to influence the construction industry and university programs. As noted above, the culture and image must be changed. This can start with university programs and even school aged children. By increasing the number of female students, this increases the number of potential female professionals with the needed skills and abilities for either industry or academics. Fielden et al. (2000) offer a method to help increase the number of female students. Fielden and colleagues propose several options for increasing construction awareness in young, school age children by having visits and career events at school, having field trips and construction site visits, and have current construction employees bring their child to work. This is all focused on informing young children of the construction industry so when college age is reached, they will pursue construction related degrees. Fielden et al. also offer a suggestion more directly applied to college aged individuals. This would be to have companies offer scholarships and help to attract students to the construction education. Thus, it is very important that high school counselors also help bring awareness to students applying for colleges (Moore, 2006).

Other efforts being made to attract women to these types of programs at universities are events like Women in Engineering Discovery Days and Women in Engineering Programs. These events tend to be university specific as the two examples are Purdue University and University of Texas, respectively. Additional opportunities are options conferences which focuses on having professionals come and network with upper level students and first year initiative which gives first year females students an upper level mentor (Menches & Abraham, 2007). Last, it is important to have counselors and advisors in high schools and community colleges informing students of the opportunities and career paths that could be taken in the construction industry (Moore, 2006). Not only does this raise awareness of the options but this would help increase female students because only 1 of 24 women actually enters into the construction management major as noted in one study (Moore & Gloeckner, 2007). All others were either second degrees or transfer students.

Moore and Gloeckner (2007) offer many suggestions for recruitment tactics to increase female involvement in these programs. Most of these share similar characteristics to the method proposed by Fielden and colleagues (2000) in that professional should participation in local schools and construction education should be support by community college and high school advisors. Another suggestion for recruitment, however, is to let any major take introduction to construction courses. This could greatly increase awareness and potential new majors in the construction field, especially if a student is undecided or just picked a major because they felt obligated.

There are many variables that influence women choosing construction management and similar degrees. Several of these variables are high confidence, family, friend, and teacher support, math and science high school coursework, ignoring stereotypes, and enjoying the hands-on opportunities presented to obtain experience (Garner, 2003). Other variables are more specific like being raised in a family where gender roles were not specified, having self-efficacy, and being included in the group as person, not a minority (Moore & Gloeckner, 2007). Thus, it is important to implement changes in recruiting and keeping in mind individual difference to increase female students which will, in turn, increase female participants in faculty and industry.

2.2 Female Faculty

The literature discussing female faculty members in construction management programs is unfortunately very limited. One study noted several reasons why female faculty members in construction and other similar programs are lacking (Committee on Maximizing, 2000). Several of these are:

- Women are promoted less frequently
- Women are paid less
- Women hold fewer leadership positions
- Women receive less support and fewer resources

These limitations are all in context to women's male counterparts in the faculty. Thus, it is important that recruitment and retention become a priority. Several universities (i.e., Cornell, Massachusetts Institute of Technology, and University of California – Berkeley) are attempting to remove or reduce the institutional barriers that slow women's promotions and advancement at universities. These steps can involve adding new positions such as Associate Dean for Diversity as Cornell did or targeted hiring (Menches & Abraham, 2007). By implementing these changes, women will be paid fairly and given the same opportunities which would make the faculty positions more appealing.

Positive ways universities already address these issues are by hosting lunches that focus on mentoring for women and by focusing research efforts on ways to increase female involvement. Organizations both internal and external to universities are taking an interest and active role in promoting women as faculty members. University of Texas created a strong internal program, Engineering Faculty Women's Organization (EFWO), with the intent of recruiting and retaining women faculty members, increasing women involvement in leadership positions, and increasing faculty mentoring opportunities (Menches & Abraham, 2007). One such external organization would be Women in Engineering Programs and Advocates Network (WEPAN). This is a non-profit organization that is focused on helping women be more successful and involved in engineering and construction industries (WEPAN 2005). The organization's direct involvement in faculty is noted in their Faculty for the Future program that helps increase women and minorities who are underrepresented in these programs. All universities can benefit from creating internal or receiving help from external organizations to increase female faculty numbers and involvement.

3. METHODOLOGY

The Associated Schools of Construction (ASC) website was utilized to find an accurate list of construction management programs at colleges and universities in the United States. Specifically, ASC defines eight regions and all but the eighth, International, were used for this study. The regions consist of Northeast (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia), Southeast (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, Virginia, and Tennessee), Great Lakes (Illinois, Indiana, Kentucky, Michigan, Ohio, and Wisconsin), North Central (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota), South Central (Arkansas, Louisiana, Oklahoma, and Texas), Rocky Mountain (Alaska, Arizona, Colorado, Idaho, Nevada, New Mexico, Montana, Utah, and Wyoming), and Far West (California, Hawaii, Oregon, and Washington; Associated Schools of Construction, 2013). From these regions, a 128 schools offered construction management or comparable programs.

When focusing on the student populations, 63 schools offered sufficient information. When considering the student population, both undergraduate and graduate levels and part and full time are included. The number of male and females in the programs were identified by utilizing the facttbooks found on university websites. A brief inquiry to the university was sent via email if the information found in the facttbook was insufficient.

The ASC website and same regions were used to find faculty data. The regions and universities were examined to provide information about female faculty members. This information was obtained by searching universities websites to find the construction management program. The list of faculty members was then closely examined to determine male to female ratios in department. The obtained information was divided in a variety of categories. Specifically, full time, adjunct, part time, lecturer/instructor, and visiting. Furthermore, the number of males and number of females for each category were noted separately.

After obtaining the information, the data was analyzed to find trends across regions and in sum. This highlights potential problems areas and strengths. It is important to know the current state because it lays the framework for improvement.

4. RESULTS

Female students were found to be drastically underrepresented in construction management programs. A total of 10,264 students were included in this study from 63 universities. From this, only 724 or 6% were female students.

Figure 1 shows the male to female breakdown by both undergraduate and graduate levels. This indicates how females are underrepresented at both levels but more so at the undergraduate level. At the graduate level, 21% of students are women while only 6% are at the undergraduate level.

Another analysis was conducted to determine the female student enrollment rates by region. As shown in Figure 2, the region with the lowest female enrollment is Rocky Mountain Region (1%) and highest is South East Region (12%).

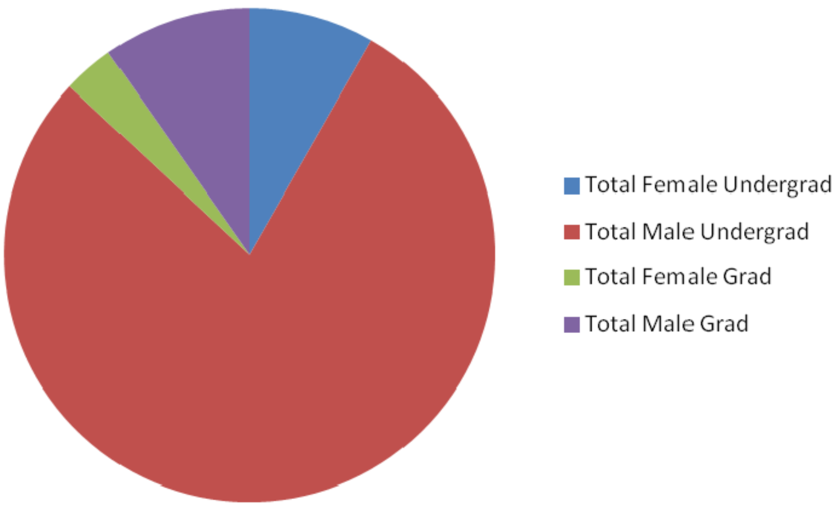

Figure 1: Male and Females in Undergraduate and Graduate Levels

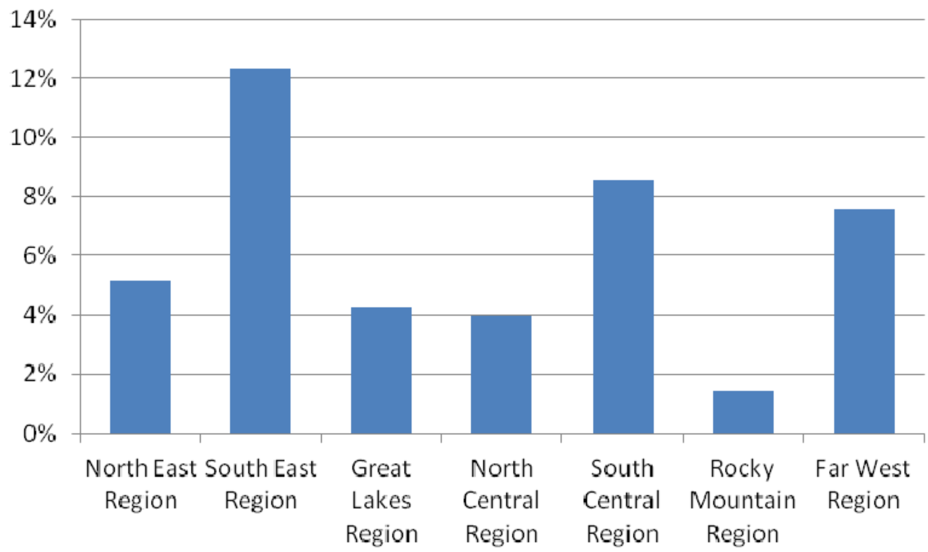

Figure 2: Female Enrollment Percentages by Region

As shown in Figure 3, 175 or 16% of faculty members are female out of a total of 1073 faculty members. This includes all faculty categories. Additionally, 115 or 66% of women are full time faculty.

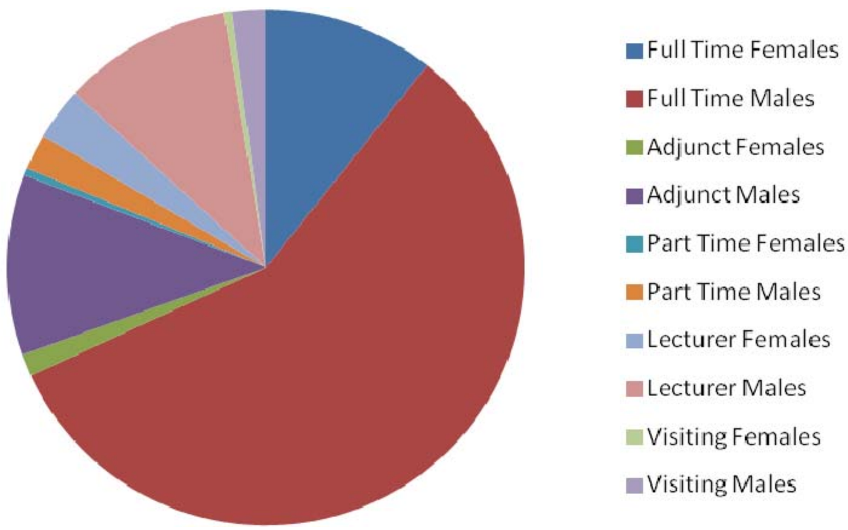

Figure 3: Comparison of all Faculty Members

Faculty results show a consistent trend across all regions. As shown in Figure 4, the total percent of female faculty members is very stable across region. However, every percentage is below 20% indicating the need for growth.

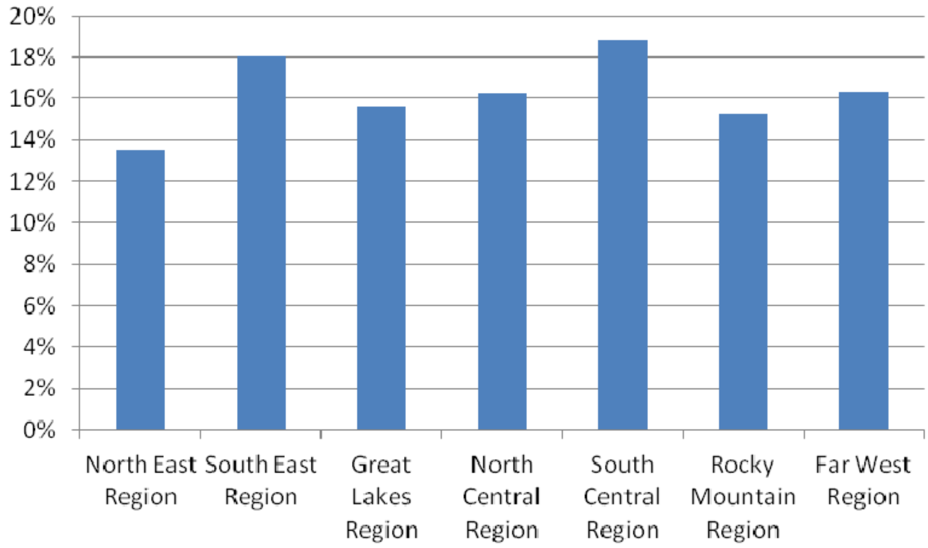

Figure 4: Percent of Female Faculty Members by Region

5. CONCLUSION

Female students are drastically unrepresented in universities especially at the undergraduate level. It is vital that students are informed and recruited about the construction industry. Having the knowledge of the construction management major is useful but supplementing that with knowing potential career paths and a realistic job preview is fundamental to increasing these enrollment rates. This can be done by following the suggestions set forth by Fielden and colleagues (2000) and Moore and Gloeckner (2007). Women are the untapped resource for future. If changes do not start in academia, women will continue to be so. Thus, it is important that steps be taken to have successful female graduating students start contributing to the industry.

Female faculty members are also underrepresented in academia. However, there is a more consistent trend across regions for employment rates. To increase the levels of female faculty members it is important that universities note reasons identified above (Committee on Maximizing, 2006) and take the proper steps to ensure fair treatment and equitable pay and opportunities. These findings did indicate the majority of female faculty were, in fact, full time. This is important because it shows women being given similar opportunities as men.

It is also important to note that many universities did not employ any women. Even adding one or two women to the faculty would greatly increase knowledge and diversity but also increase female students by giving them a mentor who understands the pressures of the male-dominated industry. If every university added one woman that would mean 128 women would be joining the construction management program. This would increase the demand and potentially draw in more female students.

There were several limitations with this research. First, the information for construction management enrollment rates was very limited and was not obtained equally across regions. Also, there tended to be estimates or number of students who had graduated the previous semester. The challenge to obtain the correct information consistently across all schools still exists and will need to be overcome for future research. One way to resolve this would to be to send a formalized survey to participants with an appropriate response wait time. This research was conducted utilizing sources published by the university and future research may obtain more accurate information by going directly to the departments, again, with adequate time for responses.

Another limitation is the lack of available literature on female faculty members in construction management programs. The research available on female professionals in the industry can only be generalized to a certain extent. It is important to have further research identify variables that influence faculty versus industry career paths for women.

Future directions for this project would include obtaining more information about students to repeat the comparisons and identify trends. Also, the data set does identify universities that lack female involvement entirely. These locations could be used to implement recruitment and retaining strategies. A follow up study could then be conducted to determine levels of success.

Furthermore, the differences in female enrollment rates for undergraduates and graduates needs to be research furthered. The male to female ratios is higher for graduates and if factors could be identified to indicate why, that knowledge could then be implemented to attract females at the undergraduate level. Regardless, the intent of this research was to determine the state of females in all levels of academia and lay the foundation for future research.

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DISCUSSIONS ON APPLYING TEXT MINING TECHNIQUES TO DISPUTE DOCUMENTS IN TURKISH PUBLIC CONSTRUCTION PROJECTS AND A NEW APPROACH

Ismail C. Yılmaz
Istanbul Arel University, Istanbul, Turkey, icyilmaz@gmail.com

Attila Dikbaş
Istanbul Technical University, Istanbul, Turkey, dikbas@itu.edu.tr

Abstract

When the disputes in public construction projects are not settled through negotiation participants may apply to arbitration, council or litigation. The disputes that have been adjudicated are recorded as a written matter in their archives. These documents are critical in terms of preventing future conflicts from turning into disputes. Project participants who want to minimize the risk of facing any disputes or who want to know how to tackle disputes should go through all documentation and look for similar cases. However it is a big challenge for participants who have little experience and knowledge about construction sector and its technical concepts. Accordingly it would be a useful solution to categorize such kind of documents automatically. This study presents a benchmarking with the previous studies in which the construction documentation is classified automatically in construction information technology. The most successful text mining techniques have been applied to documentation relating to public construction disputes that has been gathered from "Turkish Supreme Board of Infrastructure and Construction", the results are discussed and a new approach has been presented.

Keywords: data mining, construction disputes, public projects, text mining.

1. INTRODUCTION

The rapid rise in construction industry at global scale has been accompanied by a great deal of disputes and claims. According to statistics obtained from judicial records in Turkey, which is among the countries with highest increase trends, there has been an increase of approximately 12% in the number of lawsuits that are opened or submitted pursuant to dismissal throughout the year in relation to construction, expropriation, demolishing and similar works [1][2]. The public projects which comprise a significant portion of construction works in the country are also impacted by the said increase. Accordingly any progress that may eliminate conflicts and disputes to arise in public projects may result in significant time and cost reduction both for the industry and the country. The primary institution which may act as arbitration board in public construction project related disputes in Turkey is Turkish Supreme Board of Infrastructure and Construction under the roof of Ministry of Environment and Urbanization. It plays active role in settlement of disputes between the contractors and public institutions. The public contractors willing to understand the overall tendency of the Turkish Supreme Board of Infrastructure and Construction regarding their possible disputes with public employers would primarily like to perform a case retrieval effort. However understanding dispute documents which are written in an extremely official language with a great deal of technical phrases requires significant efforts. Therefore automated classification and delivery of such documentation to the addressees is critical. Systematic classification of legal documents and identification of precedents has been improved for long. With outstanding masses of archives including such documentation, automation of the said classification and identification has gained pace recently. This study classifies 49 documents regarding disputes in public projects in Turkey which are obtained with special permission from the Turkish Supreme Board of Infrastructure and Construction, utilizing the existing text mining techniques, discusses applicability of these techniques to this case and intends to propose a new model approach for this case.

2. LITERATURE REVIEW

Previous studies indicating that classifiable documentation can be categorized using text mining techniques have inspired development of this study. It is observed in the course of literature review that these techniques can be utilized for also classification of instruction documentation. On grounds of their studies, Arditi et. al. (1998) concluded that disputes in construction works are caused by various complicated and interconnected factors which are difficult to interpret. With the aim of predicting dispute rulings in construction industry using the artificial neural networks technology, they gathered the rulings of Illinois Court of Appeals in the last 12 years. Fan and Li (2011) conducted a research on similarities between the accident case reports in Hong Kong constructions using the text mining techniques and argued that accident rates could be reduced thanks to this know-how and experience obtained easily this way. Caldas et. al. (2002) conducted a study which uses classic machine learning techniques in construction information systems, and proposes a model prototype according to the results obtained. In another study that Caldas et. al. (2003) performed; they introduced a methodology for the hierarchical classification of construction project documentation. These studies suggest that text mining techniques can be employed in construction information system and constitute a basis for the benchmarking that we perform for the case study in this research. Each study involves testing on the basis of methods that are similar in terms of size reduction, number of features, number of cases, weight of terms and classifier type. Table 1 presents the most successful results obtained in these three studies and compares four different parameters used in text categorization efforts. These parameters are explained in Section 3 which dwells on case study efforts. Section 3 covers the stages and results of case study efforts with the parameters used for this case on the basis of successful efforts.

	Instance Quantity (a)	Dimensionality Reduction (b)	Term Weight (c)	Best Classifier (d)
(Fan and Li) (2011)	360	LSI	TF*IDF	kNN (Cos. sim.)
(Caldas and Soibelman)(2003)	3030	No DR	TFC	SVM
(Caldas et. al.)(2002)	845	IG	TFC	SVM

Table 1: The Most Successful Results Obtained in Studies on Construction Information Technology

DR: Dimensionality Reduction
LSI: Latent Semantic Indexing Method
IG: Information Gain
TF*IDF: Term Frequency*Inverse Document Frequency Term Weight
TFC: Normalized Term Frequency*Inverse Document Frequency Term Weight
KNN: k-Nearest Neighborhood Algorithm
SVM: Support Vector Machines Algorithm

3. CASE STUDY

3.1. Preparation and Compilation of Data Documentation (a)

For the purpose of this study, data sets to which text mining techniques can be applied are decided to be the rulings on dispute settlement of the Turkish Supreme Board of Infrastructure and Construction [3] which acts as a kind of arbitration board and is the decision maker with greatest authority in disputes experienced in public construction projects in Turkey. As a first step, 82 documents that were obtained from the archives of the Turkish Supreme Board of Infrastructure and Construction in hard copy were classified to ensure efficient performance of the study. Some construction projects may involve multiple disputes that remain unsettled due to nature of business. Taking this into consideration, documents that cover subjects of multiple disputes are excluded from the scope of study. For ensuring the integrity of scope, documents in which dispute cannot be classified exactly, documents which are considered to include patterns that cannot be differentiated by the machine, and documents that cover certain disputes specific to some unclassifiable projects are not included. As a result, 49 documents were included in the study. All these documents that were available in hard copy were taken into transformation processes and were digitalized in .txt format. The documents were then processed with Natural Language Processing (NLP) techniques including but not limited to removal of punctuation, chunking and parsing, stop-word removal. In this study, NLP techniques were applied using "txt2arff" which is package software for texts in Turkish. With all documents categorized in a way that will allow each to represent a single type of dispute, all documents were taken into analysis in terms of subject matter, claims and rulings in the process of categorization of subjects of disputes which would be labelled on each document. As a result, the most common types of disputes were identified and became the main categories. This process of categorization was finalized by obtaining expert opinion with active involvement of public supervising engineers and representatives of contractors engaged with public construction works, who are the major profiles among industry participants.

3.2. Dimensionality Reduction (b), Term Weighting(c) and Classifiers (d)

Vector space matrix created with documents using the terms in documents is presented in Figure.1. Methods of feature selection or feature removal are applied to text mining studies where terms have a significant weight. Feature selection methods require selection of the most qualified and informative features among those available in documents. On the other hand, feature extraction is applied by compiling the features from new terms which are synonym, homophone or ambiguous without obtaining features from documents. The most common methods of feature selection are IG, CHI. Examples to applications of feature removal methods include Latent Semantic Indexing, Term Clustering. Caldas et. al. (2002) applied IG (Information Gain) method in their study in reference to studies of Yang and Pedersen (1997) and Joachims (1998). Caldas and Soibelman (2003), on the other hand, obtained more successful results by implementing dimension reduction in comparison to IG method that they implemented in their previous study. They were surprised by the results which they accounted for the existence of few number of irrelevant index terms on the basis of Joachims's explanations (1998). On the grounds of these conclusions, this study compares the method of dimension reduction with a glossary developed by selecting or creating the features manually with an emphasis on particular structure of Turkish public construction sector terminology in order to ensure differentiation, with the two methods of dimension reduction explained above considering that more successful results can be obtained with no-feature removal or LSI feature removal. This method shall be referred to as manual feature selection hereafter. Among term weighting methods, tf* tf-idf and tfc were compared as used in previous studies.

$$N = \begin{vmatrix} a_{11} & a_{12} & a_{13} & \dots & a_{1j} \\ a_{21} & a_{22} & a_{23} & \dots & a_{2j} \\ a_{31} & a_{32} & a_{33} & \dots & a_{3j} \\ \dots & \dots & \dots & \dots & \dots \\ a_{i1} & a_{i2} & a_{i3} & \dots & a_{ij} \end{vmatrix}$$

i : Number of documents, j : Number of qualified words, a_{ij} : Weight of terms

Figure 1: Term Weighting Matrix of Documents and Terms

Ultimately texts were evaluated within the frame of classification tests with WEKA 3.6 in different algorithms such as Decision Tree (DT) and Naïve Bayes (NB) in addition to successful classification algorithms in the comparison studies, namely kNN and SVM.

3.3. Results, Discussions and Some New Approach

The most successful result obtained from various combinations of dimension reductions, term weights and classifiers is shown on Table 3. Accordingly the test performed with the combination of manual feature selection, tfc term weighting and DT classifier yielded the most successful result which is 88.23%. Success rates of tests performed with various classifiers are presented on Table 4.

Dimensionality Reduction	Instance Quantity	Term Weight	Classifier
Manuel Selection	49	TFC	DT

Table 3: The result obtained with most successful configuration

k-NN	SVM	NB	DT
35.29	64.70	58.82	88.23

Table 4: Results of tests performed with manual extraction, TFC weighting method and various classifiers

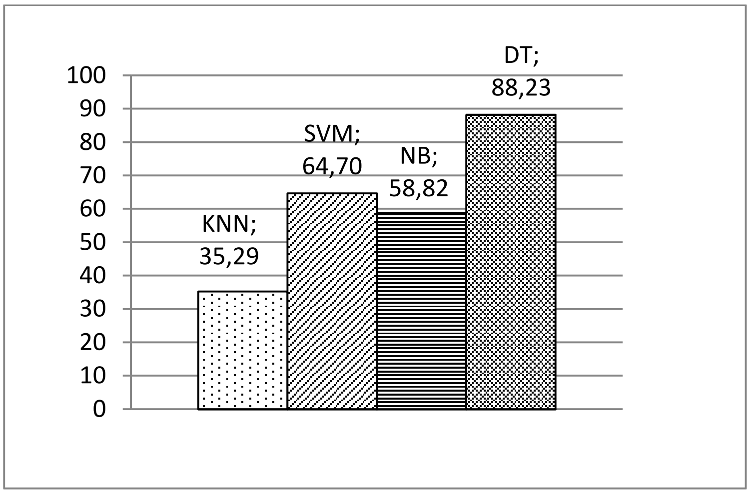

Figure 2: Results of tests with manual extraction, TFC weighting method

Evaluation of all test results indicate that among all studies on categorization of reports on Turkish public construction sector disputes, manual feature selection which involves preparation of a glossary for automated classification yielded better results. This could be accounted for the remoteness of the official Turkish construction sector terminology in documents to the dimension reduction method based on a certain mathematical algorithm or for its specific nature. In term weighting method, a normalized term weighting as is explained by Caldas and Soibelman (2003) study has yielded more effective results. Obtaining better results with DT among other classifiers could be considered surprising. Nevertheless this could be accounted for a different construction environment and style inherent in this case study.

According to the evaluation of four other studies along with the present study, it is possible to conclude broadly that all studies tend to yield different results. Therefore, given the different climate of Turkish public construction projects and different structure of related contracts, in order to obtain better results and to ensure healthy processing of case retrieval model and hierarchical document classification in our next study, a hybrid approach involving dimension reduction, term weighting and classifier techniques which all yield more successful results in this study among text mining techniques applicable to Turkish construction dispute documents can be considered. For instance Information Gain, which is a method of feature selection, yielded significant results in tests involving various combinations of dimension reduction methods. It is also possible to consider that a model which involves manual selection and IG in combination and in which normalization of term weighting is increased could be efficient. On the other hand, it is believed that weighting terms in universe of dispute categories and classification of new documents on the basis of such term weighting rather than usual classification of documents weighted in the universe of terms based on similarities could produce effective results. The prototype of automation model that we aim to present in our next study is generated on the basis of these principles and preliminary testing performed by extending the same data set yielded more successful results.

4. CONCLUSIONS

This study is grounded on the previous three studies where text mining techniques were applied to construction documentation and presents a benchmarking and a new model approach on this basis. Benchmarking portion of the study examines different results obtained from three other studies. Parameters that yielded the most successful results in those studies were applied to documentation of rulings of the Turkish Supreme Board of Infrastructure and Construction which acts as arbitration board in disputes relating to Turkish public construction projects and it yielded different results from other studies. This is accounted for the particular structure of Turkish public construction contracts and unique nature of construction projects in Turkey. From this perspective, it is proposed that the text mining techniques that will be applied to dispute documentation of Turkish public construction sector should be a hybrid model with parameters collating this study with the prior studies. Our primary aim with such a model is to develop an automation model that will facilitate the case retrieval study for Turkish Public Construction Project contractors and employers, and allow them to better predict the rulings of the Turkish Supreme Board of Infrastructure and Construction. The details and test results of this model will be demonstrated in our next study.

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A LESSONS-LEARNED-BASED UNIVERSAL PROBLEM SOLVING MODEL FOR CONSTRUCTION ENGINEERING

Wen-der Yu
Chung Hua University, Hsinchu, Taiwan, R.O.C., Email: wenderyu@chu.edu.tw

Pei-Lun Chang
CECI Engineering Inc., Taipei, Taiwan, R.O.C., Email: peilun@ceci.com.tw

Shun-min Lee
CECI Engineering Inc., Taipei, Taiwan, R.O.C., Email: peilun@ceci.com.tw

Abstract

This paper presents a Universal Construction Problem-Solving Model (UCPM) based on historical lesson-learned files to assist construction engineers in finding the preliminary solution of a construction problem. The proposed UPSM is developed using an induction method based on 631 historical lesson-learned files collected from a leading engineering consulting firm in Taiwan. The proposed UCPM integrates Construction Project Management Body of Knowledge (CPMBOK), Theory of Inventive Problem Solving (TRIZ) and Data Mining (DM), so that the management parameters (PMs) and Problem-Solving Principles (PSPs) are defined and derived. Finally, a UPSM is obtained consisting of two types of PMs and a set of 76 PSPs. After tested with 54 real world cases, the proposed UPSM is verified to achieve 96% overall successful problem-solving rate. It is concluded that the proposed UPSM provides a useful tool to construction engineers for directing problem-solving principles regardless of the complexity and diversify nature of the problems.

Keywords: knowledge management, problem solving, engineering consultants, lessons learned.

1. INTRODUCTION

Construction engineers are facing various emergent problems in their daily works. In solving such problems, they usually rely on previous knowledge and experience for creating solutions. By using a knowledge management system (KMS), the lesson-learning process of problem solving can be documented or stored and reused. Constant creation and accumulation of new lesson-learned files (LLFs) are required to facilitate the resolution of problems. Using the community of practice (CoP) model for problem-solving application is commonly found in many commercial KMS applications. It is also observed in many major engineering consulting firms both in Taiwan and other countries.

The problem-solving process of CoP in a KMS can be described as follows: first, a problem is raised and posted in the CoP by the engineer (namely *Questioner*) who confronts the construction problem; then, responses are provided from the domain experts (namely *Responder*); after the suggested solution has been adopted and the problem has been solved, the *Questioner* organizes the solution into a standardized and reusable format called lesson-learned file (LLF). Generally, a LLF comprises at least three components: (1) problem description; (2) solution process; and (3) result evaluation. As construction projects proceed, engineers are regularly required to solve new engineering problems based on their past problem-solving experience no matter the problems were ever encountered or not. From this perspective, summarizing or extracting reusable principles from previous problem-solving experiences can be more beneficial and reusable than just providing historical LLFs.

The reusable problem-solving principles adopted by construction engineers are very similar to the Altshuller's theory of inventive problem-solving (TRIZ) (Altsuller, 2002), a method of solving technological contradictions. Although TRIZ has been applied successfully to various fields, Yeh *et al*. (2010) showed that the engineering parameters and inventive principles of TRIZ are more suitable for solving technical or technological contradictions than for construction problems. Construction problems are generally solved using management measures and techniques, implying that a problem-solving theory suitable for construction engineering problems needs to be developed.

This research aims at summarizing construction problem-solving principles from historical LLFs to propose a universal construction problem-solving model (UCPM) that is reusable and suitable for construction engineering. The rest of this paper is organized as follows: relevant literature of problem domain and related fields are reviewed first; it is followed by the detailed description of model development and versification of UCPM; then two application examples of the proposed UCPM are demonstrated; finally conclusions and recommendations are addressed at the end of the paper.

2. LITERATURE REVIEW

2.1. Problem-Solving and Lessons-learned

Problem-solving is the most significant issue for many construction engineering. Planning, design, construction, and even project management are integrally related to problem-solving activities. Li and Love found construction problems pose several characteristics (Li and Love, 1998): ill-structured nature, inadequate vocabulary, minimal generalization and conceptualization value, temporary multi-organization, uniqueness of problems, and difficulty to reach the optimal solution.

Lessons-learned can be referred as experiences that have gone through in the past. The lessons learned through experience can help identify problem solving models for recent events and link them with previous events (Salmon and Siegel, 2001). While solving the problems encountered in a construction firm, the solution is usually generated by knowledge creation activities of the staffs, based on Nonaka's theory of knowledge creation spiral (Nonaka, 1994). Knowledge management systems (KMSs) provide an effective means for recording the problem-solving process. Such records are structured and stored so that that can be reused in solving similar problem in the future.

2.2. Theory of Inventive Problem Solving (TRIZ)

TRIZ is the acronym for the Russian term *Theoria Resheneyva Isobretatelskehuh Zadach*. It is a method employing innovative thinking to solve technological contradiction problems. It was proposed by the patent reviewer of former USSR, Genrikh S. Altshuller while reviewing the patents: first Altshuller defined 39 common engineering parameters (EPs) and established the contradiction matrix based on the contradictions that frequently emerged between parameters; then he concluded 40 inventive principles to solve the contradiction, based on the evidence found in the 40,000 patents; finally a systematic procedure was proposed for identifying the inventive principles most likely to solve of a new technological contradiction (Altshuller, 2002). TRIZ has been successfully applied in many fields (Mann, 2001; Terninko 2001; Retseptor, 2002). Although some technological applications were reported in the construction area, former research has found that TRIZ failed to achieve widespread application in solving general management-type construction problems (Yeh, *et al*., 2010). It indicates that a construction-specific model for problem solving is desirable.

2.3. Project Management Body of Knowledge (PMBOK)

In searching for the characterizing management parameters (MPs) and problem-solving principles (PSPs) of general construction problems, three internationally adopted standards for construction project management were reviewed, including the Project Management Body of Knowledge (PMBOK) (PMI, 2008), the IPMA Competence Baseline (ICB) (IPMA, 2006) of the International Project Management Association (IPMA), and the CIOB Education Framework of the Chartered Institute of Building (CIOB) (CIOB, 2005). Among those, the Construction Extension of the Project Management Body of Knowledge (CPMBOK) (PMI, 2007) is finally selected as the primary reference in this research due to its popularity in the international construction community. PMBOK is an officially recognized standard by the Project Management Institute (http://www.pmi.org), which documents the established norms, methods, processes, and practices in project management specialized fields (PMI, 2008). Based on PMBOK, PMI published its Construction Extension of Project Management Body of Knowledge (CPMBOK) (PMI, 2007) with four supplementary knowledge areas including safety management, environment management, financial management, and claims management. The CPMBOK is not only a body of knowledge more suitable for managing construction projects but also becoming an international language used worldwide to define the required knowledge fields, process groups, operational processes, and useful tools and techniques for construction project management.

2.4. Data Mining (DM)

As the advent of the Internet and database technologies, data acquisition has become very handy. With the automatic and globalized searching tools, the data explosion problem has become a crucial issue for contemporary data managers (Han and Kamber, 2001), which may easily overwhelm the data users. In order to tackle the problem of data explosion, data mining (DM) technologies have been researched and proposed by previous researchers (Han and Kamber, 2001; Fayyad and Uthurusamy, 1996). The purpose of DM is to extract previously unknown or hidden rules, constraints, and regularity information from databases with a large volume of historical transactions that could have application value in the future (Fayyad and Uthurusamy, 1996). Construction problems are industry-specific, which require the collection and analysis of the domain knowledge for effective solutions. Using DM to identify specific and common rules and principles from past or historical experiences and cases provides a means to rank the solution principles in order to increase problem-solving efficiency. Moreover, the significance of association rules identified by DM techniques also provides an alternative method to verify the appropriateness of problem-solving principles identified.

3. RESEARCH METHODOLOGY

As TRIZ theory provides a generic framework for a problem-solving model (including the proposed UCPM), this research adopts similar approach that was employed by Altshuller in developing TRIZ theory. As a result, the essential issues for establishing UCPM would be the acquisition of historical LLFs for problem solving, identifying the characterizing parameters (i.e., MPs) and problem-solving principles (i.e., PSPs), and establishing the relationships among MPs and PSPs. In this regard, the historical LLFs of former problem-solving cases are collected as the knowledge source from the KMS of a local leading engineering consulting firm. The collected LLFs are then characterized with a set of vocabulary mainly elicited from CPMBOK for describing the problem MPs and the PSPs. In order to verify the appropriateness of the quoted vocabulary (for characterizing parameters and problem-solving principles of the problems), domain experts with abundant experience and expertise in solving related construction problems are consulted to establish a Construction Problem-solving Matrix (CPSM). The CPSM provides a look-up table associating the MPs and PSPs in finding the problem-solving principles for the target problem. After revision and verification with domain experts, a DM technique is employed to identify the association rules from historical LLFs. The results are used to rank the priority of problem-solving principles in the CPSM. Finally, the Universal Construction Problem-solving Model (UCPM) is proposed to equip the construction engineers with a means to locate reference solution principles while they are confronting emergent construction problems. In order to verify the validity and applicability of the proposed UCPM, 60 new real world construction problems encountered by engineers in the field are employed for model testing. The testing results are then discussed in depth to conclude the findings of the study.

3.1. Lessons-Learned Acquisition and Selection

A top ranking engineering consulting firm, CECI Engineering Consultants, Inc. (http://www.ceci.com.tw/english/), namely CECI hereafter, has been selected as the industrial partner to collect historical LLFs. A wide range of 908 representative construction problem-solving LLFs were collected from 2004 to 2010. While investigating the content of LLFs, it was found that some cases are related to schedule delays (Time Management) but the problem description was focused on how to resolve the dispute between the project participants; it is then re-classified into the category of Claim Management. Such situations are commonly encountered in the collected cases, indicating that a more specific classification system is desirable to replace the 13 knowledge areas of CPMBOK.

In order to improve the quality of the collected data, the study established the following criteria for expelling the unqualified cases: (1) incomplete data—e.g., incomplete solution description or not evaluated by the solution adopter; (2) non-engineering relevant problem—e.g., computer related or administrative problems; (3) non-urgent problems—e.g., word processing or software usage problems; (4) lowly scored cases—e.g., scored below 2 (40%) in terms of Likert 5-point scale; and (5) low data reusability rates—rated by the manager of the relevant department. After screening with the above criteria, 277 cases were excluded from the study, leaving 631 cases for in-depth analysis in the research.

3.2. UPSM Model Development and verification

The model development procedure is comprised of 8 steps: (1) Classification of problem classes; (2) Analysis of problem occurrence stage in project lifecycle; (3) Determination of Solution Principles; (4) Constructing Construction Problem-Solving Matrix; (5) Development of preliminary model of UCPM; (6) Prioritizing with data mining; (7) Model verification; and (8) Expert validation. Following describes the detailed development process of UCPM:

1. Classification of problem classes

Originally, the 631 selected LLFs were classified using the 13 project management knowledge areas based on CPMBOK, and found server overlaps problems exist in such a classification. It implies that the selected classification system is not suitable for characterizing the domain problem effectively. An improvement method is employed based on the description keywords of the problem. By this way, the LLFs originally classified into 13 knowledge areas are re-categorized into 39 sub-areas (according to the identified keywords in problem descriptions); then, the similar sub-areas are grouped and aggregated to yield 11 characterization problem classes (i.e., similar keywords are grouped together), including: (A) Cost estimation; (B) Insurance/Bond; (C) Contract; (D) Safety; (E) Cost control; (F) Tendering/Documentation; (G) Dispute; (H) Quality/Technical; (I) SPEC/Standard; (J) Schedule; (K) Resources/Materials. The 11 characterization problem classes are defined as Management Parameter-I (MP-1).

2. Analysis of problem occurrence stage in project lifecycle

The occurrence stage in the project lifecycle has obvious impact on the solution adopted. For example, a quality problem discovered in the design stage will trigger a design modification and specification revision; however, it needs costly rework after construction work has proceeded. As a result, the second management parameter (MP-2) for characterizing a construction problem is to describe the occurrence stage of a construction problem. This research adopts the five process groups of CPMBOK as a standard for project lifecycle analysis: initiating, planning, executing, monitoring and controlling, and closing process groups. Each of the LLFs is analyzed and labeled with an associate process group. After labeling, it is found that no urgent problems occurred in the initiating process group, 363 cases (58%) occurred in the planning process group, 82 cases (13%) in the executing process group, 26 cases (4%) in the monitoring and controlling process group, and 160 (25%) cases in the closing process group. The data indicates that urgent problems in CECI occur primarily during the planning (58%) and the closing (25%) processes. This may be due to the nature of an engineering consultant where design and planning play the major roles in its business activities.

3. Determination of Solution Principles (Tools and Techniques)

After characterizing the construction problems, the next step is to determine the problem-solving principle (PSP) adopted in the historical LLFs. This is a challenging task, since the summarized solution for the quoted construction problem has been documented by the *Questioner* of the problem and articulated in his own language. Different *Questioners* may describe the same solution in different way. In order to reach a common language for defining problem-solving principle, this study adopts the tools/techniques of the processes in CPMBOK as a standard to define the adopted PSPs in the selected LLFs.

After carefully reviewing all 631 LLFs, it is found that most problem-solving principles (PSPs) can be determined with the tools/techniques of the relevant processes in CPMBOK, while 26 LLFs (4.12%) cannot be properly assigned. Among those, the PSPs of 21 LLFs can be defined with tools/techniques in the other process groups of CPMBOK, while the rest 5 LLFs cannot be interpreted appropriately. As a result, 5 additional PSPs are added.

4. Constructing Construction Problem-Solving Matrix (CPSM)

After determining the relationships among MP-1, MP-2, and PSPs of the 631 historical LLFs, the CPSM is constructed to serve as a look-up table for directing applicable problem-solving principles (PSPs) given a set of preconditions (MP-1 and MP-2).

5. Development of the preliminary model of UCPM

A construction problem-solving procedure is established by integrating MP-1, MP-2, PSPs, and CPSM. Such a procedure along with the associated management parameters (MP-1 and MP-2) and problem-solving principles (PSPs) constitute the preliminary model of the proposed UCPM. The problem-solving process of the proposed UCPM is briefly described as follows: when a problem is posted, it is first classified based on the type of problem to identify the Problem Class (PC); next, the problem is classified according to the time when it occurred to identify the Process Group (PG); finally, the PC and PG are used to query the CPSM into to obtain the recommended PSP within the matrix. For more detailed information, the engineer can refer to the historical LLF in database associated with the recommended PSP.

6. Prioritizing with data mining

After constructing the preliminary UCPM, a DM technique is employed to analyze the support, confidence, and importance of each managing parameter (MP) and solution principle and to prioritize the applicable PSPs in CPSM. The primary objective for employing DM is to dig out the interesting patterns. Such a task can be very time-consuming if it is done by human manually.

This study uses the “association rule” technique to mine the nine attributes and identify the association among the attributes. Examples of DM results include: (1) When a problem with “bid invitation or submission procedure and documentation” occurs in the planning process, the “sample, form, standard” technique is frequently used as a solution; (2) When a problem with “engineering insurance and guarantee” occurs in the planning process, the “planning meeting and analysis” tool is frequently used as a solution; and (3) When a problem with “cost control” occurs in the executing process, the “expert judgment (added)” tool is frequently used as a solution.

7. Model verification

In order to verify the proposed UCPM, 60 newly posted construction problems were selected for model testing. According to the screen criteria described in Section 3.1, six unqualified cases were expelled. The rest 54 cases (90%) are used as verification cases. Each case was analyzed for problem classification (PC): (1) 3 cases (6%) are classified as “A. Engineering Estimates or Appraisals”; (2) 1 case (1.5%) is classified as “C. Engineering Contracts”; (3) 2 cases (4%) are classified as “D. Safety Management”; (4) 28 cases (52%) are classified as “H. Quality and Technology”; (5) 13 cases (24%) are classified as “I. Norms/Standards” problems; (6) 1 case (1.5%) is classified as “J. Progress Planning and Control”; and (7) 6 cases (11%) are classified as “K. Construction Resources/Material”.

It is found that the solution descriptions for 37 verification cases (applicability rate of 57%) fully aligned with the PSPs identified in the matrix; 21 solution descriptions for the verification cases (i.e., 39%) had partially matched the suggested PSPs of CPSM; only 2 of the verification cases (4%) were unsuitable for the matrix because solution descriptions are incompatible with those identified in the CPSM for the model. Overall, 52 of the 54 cases are compatible with the PSPs recommended in the matrix, indicating that this verification has a suitability rate of 96%.

8. Expert validation

A domain expert was invited to assist with the final validation of the proposed model. The expert possessed over 13 years of practical experience in construction engineering, and held a position in the Taiwanese branch of the PMI. He has also participated in KMS problem-solving, and has an extensive understanding of CECI Engineering Inc.'s KMS operations.

The expert provided the verification cases in this study with a score between 1 and 5 based on his degree of agreement. Excluding four cases that received a score of 2 (indicating disagreement), the remaining 50 cases all received scores of 5, thereby obtaining an average score of 4.8. The expert agreed that the model was suitable for 50 of the problem-solving cases, for an overall agreement of 92.6%; the expert disagreed with the model's suitability for four cases, for an overall disagreement of 7.4%. The cases disagreed by the expert were discussed further during interviews. The expert explained the reason why the PSPs of the four cases were disagreed is because the PSPs should be (but were not) included in the CPSM. He said those four cases are very common in practice. Therefore the expert recommended that these PSPs be added to the matrix and that a mechanism for updating and expansion be developed.

3.3. Revised UCPM Model

After validation by the domain expert, the preliminary UCPM model is revised. The major components of UCPM are described in the following:

A. MP1: Problem Class (PC)

The PC items include: (A) Cost estimation; (B) Insurance/Bond; (C) Contract; (D) Safety; (E) Cost control; (F) Tendering/Documentation; (G) Dispute; (H) Quality/Technical; (I) SPEC/Standard; (J) Schedule; (K) Resources/Materials. Table 1 shows each PC category.

Code	PC	Description	# of Cases
A	Cost estimation	Estimating the price and cost of engineering	16 (2.5%)
B	Insurance/Bond	Engineering insurance and risk	3 (0.5%)
C	Contract	Contract issues.	28 (4.4%)
D	Safety	Safety management when agreements are honored for engineering	14 (2.2%)
E	Cost Control	Engineering cost control and management	27 (4.3%)

Code	PC	Description	# of Cases
F	Tendering/Documentation	Procedures for inviting or submitting bids and relevant documents	3 (0.5%)
G	Dispute	Disputes and arbitration over honoring agreements	30 (4.8%)
H	Quality/Technical	Engineering quality, including technological problems	251 (39.8%)
I	SPEC/Standard	Construction norms and standards	146 (23.1%)
J	Schedule	Engineering progress planning and control	15 (2.4%)
K	Resources/Materials	Problems related to construction resources and materials, including construction tools	98 (15.5%)

Table 1: PC categories

B. MP2: Process Group (PG)

The PGs include the following groups: (1) initiating; (2) planning; (3) executing; (4) monitoring and controlling; and (5) closing. Following the expert-assisted verification of the 631 cases analyzed and summarized by this study, one case of an urgent problem (0.1%) occurred in the initiating PG, 342 cases (54%) in the planning PG, 101 cases (15.9%) in the executing PG, 26 cases (4%) in the monitoring and controlling PG, and 165 (26%) cases in the closing PG. These research results indicate that the urgent or emergency construction engineering problems for this study primarily occur during the planning, executing, and the closing PG. Table 2 shows the PG categories.

Code	PG	# of Cases
a	Initiating	1 (0.2%)
b	Planning	342 (54.2%)
c	Executing	101 (16.0%)
d	Monitoring and Controlling	26 (4.1%)
e	Closing	165 (26.1%)

Table 2: PG Categories

C. Problem-Solving Principle (PSP)

After revision by the expert-assisted verification process, it is concluded that the 631 LLFs adopted a total of 76 PSPs. The PSP categories are shown in Table 3.

PG	PSP
Initiating	a-1 expert judgment
Planning	b-1 document check; b-2 feasibility analysis; b-3 bottom-up estimating; b-4 contract;b-5 contractual legal precedent; b-6 cost-benefit analysis; b-7 cost pooling; b-8 other safety planning tools; b-9 consultation (added); b-10 legal feasibility analysis (added); b-11 quality cost; b-12 risk information quality assessment; b-13 risk probability and conflict assessment; b-14 expert judgment; b-15 project requirement investigation; b-16 product analysis; b-17 planning meeting and analysis; b-18 precedence diagramming methods (PDM); b-19 communication techniques; b-20 communication requirement analysis; b-21 information gathering techniques; b-22 sample, form, standard; b-23 benchmarking; b-24 standard form; b-25 environmental test and simulation; b-26 analogous estimation method
Executing	c-1 safety-hazard risk analysis; c-2 safety planning tools and techniques; c-3 quality control tools and techniques; c-4 quality planning tools and techniques; c-5 quality management investigation; c-6 process analysis; c-7 safety control execution tools and techniques; c-8 environment control execution tools and techniques; c-9 expert judgment (added); c-10 communication skills; c-11 information collection and selection or extraction system; c-12 Internet (added); c-13sample, form, standard (added); c-14 customer evaluation system; c-15 selection or screening system; c-16 modification tools and methods (added)
Monitoring and Controlling	d-1mutually acknowledged modification; d-2 contract modification control system; d-3 safety-hazard risk analysis; d-4 cost modification control system; d-5 consultation (added); d-6 settle claims with insurance company (added); d-7 quality assurance tools and techniques; d-8 process statistical analysis and report methods; d-9 process comparison; d-10 risk reassessment
Closing	e-1 claim assessment or expert report; e-2 consultation; e-3 expert judgment (added); e-4 develop project completion checklist; 3-5 accounting/finance system

Table 3: PSP Categories

D. Construction Problem-Solving Matrix (CPSM)

The 631 cases are classified based on 11 PCs, 5 PGs, and 76 PSPs in the CPSM. Figure 2 shows the resulted CPSM.

Item			**PG**				
		Code	**a**	**b**	**c**	**d**	**e**
PC	**Code**	**Item** / **Category**	**Initiating**	**Planning**	**Executing**	**Monitoring and Controlling**	**Closing**
	A	**Engineering Estimates or Appraisals**		b-3,b-14,b-26(b-21)		d-2,d-15,d-24,(d-27)	e-2

Item		PG					
		Code	**a**	**b**	**c**	**d**	**e**
	B	**Engineering Insurance and Guarantees**		b-17		d-6	e-3
	C	**Engineering Contracts**		b-5,b-9,b-14		d-1,d-5,d-9,d-15, d-18,d-22,d-23	e-1,e-2, e-3,e-4
	D	**Safety Management**		b-14,b-16,b-22	c-1,c-2	d-3,d-15,d-24, d-28	
	E	**Cost Control**		b-2,b-3,b-7,b-14, b-24,b-26	c-9	d-1,d-4,d-13, d-15, d-16,d-22, d-23	e-5
	F	**Bid Invitation or Submission Procedure and Documentation**		b-22			
	G	**Dispute Settlement**		b-4,b-5,b-9,b-14	c-8, c-10	d-1,d-11,d-15, d-17, d-19,d-22, d-24,d-28	e-2,e-3
	H	**Quality and Technology**		b-1,b-6,b-8,b-11, b-12,b-13,b-14, b-16,b-21,b-22, b-23,b-25,b-26, (b-15),(b-20)	c-1,c-3, c-5,c-6, c-7,c-9, c-11, c-12, c-16	d-5,d-7,d-8,d-10,d-12 d-14,d-15, d-20, d-21,d-22, d-23, d-24,d-25, d-28	
	I	**Norms/Standards**	a-1	b-3,b-8,b-10,b-14, b-16,b-19,b-20, b-22,b-23	c-2,c-3,c-4,c-5, c-9,c-11, c-12,c-13	d-5,d-23,d-28,d-12	e-3
	J	**Progress Planning and Control**		b-9,b-14,b-18		d-11,d-15,d-22, d-26,d-27	e-2
	K	**Construction Resources/Material**		b-3,b-14,b-15, b-16,b-21,b-22	c-3,c-9, c-12, c-14c-15,c-16	d-3,d-15,d-21, d-22,d-23	

Figure 3: Construction Problem-Solving Matrix (CPSM)

4. APPLICATION DEMONSTRATION

Two cases are used to demonstrate the applicability of the proposed UCPM in solving real world construction problems. Both of the cases are emergent problems recently encountered and resolved by the engineers of CECI. The solutions to the cases have been documented in LLFs. To use the model, the problem must be classified and time-stamped to obtain the PC and PG, in order to query the CPSM. In this way, several PSPs may be obtained. These PSPs are the problem-solving principles adopted in similar past cases. The engineer (*Questioner*) can then develop the final solution based on the suggested PSPs. He/she can also refer to the related historical LLFs to learn more details about the PSPs.

4.1. Application Case I—Engineering Contract

1. Problem Description—is it required for a contractor to assign a full-time professional civil engineer (PCE) to supervise the task in a weak electronic device installation work?

2. Documented solution—(1) Weak electronic device installation work does not comply with the scope of Construction Industry Regulation (CIR), thus on-site PCE is not required, however the contract stipulates an onsite responsible personnel (e.g., project manager); (2) Such a work should comply with Communication Construction Regulation (CCR) and should

assign a full-time professional electrical engineer (PEE) based on Stipulation or Clause I; (3) Additional legal requirements from the proprietor should be outlined clearly in the contract and budgeted accordingly.

3. Application of CPSM to Identify PSPs—(1) This problem is classified under “C. Engineering Contracts,” and occurs in the “monitoring and controlling process”; (2) The final solution descriptions are “d-15 expert judgment” and “d-23 sample, form, standard (added)”; (3) This study uses the two MPs for the case, “C. Engineering Contracts” PC and the “monitoring and controlling” PG, to determine that the PSPs in the matrix are “d-15 expert judgment” and “d-23 sample, form, standard (added)”; (4) Associated LLF can be consulted for a description of “d-15 expert judgment” and “d-23sample, form, standard (added)” to solve the problem.

4.2. Application Case II—Construction Resources/Material

1. Problem Description—Please help provide the construction method and unit price information regarding the surface processing work of exposed concrete.

2. Documented solution—it is suggested to contact Contractor “A” (a contractor specialized in exposed concrete) directly. The unit price for a water mold varies generally according to the work complexity and volume (smaller volume implies higher price). Specialized contractor provide design drawings and cost estimates, see the attached (attachment provided).

3. Application of CPSM to Identify PSPs—(1) This problem is classified under “K. Construction Resources/Material,” and occurs in the “planning process”; (2) The final solution description is “b-14 expert judgment”; (3) This study uses the two MPs for this case, “K. Construction Resources/Material” PC and “planning” PG, to determine that the PSP in the matrix is “b-14 expert judgment; (4) Associated LLF can be consulted for a description of “b-14 expert judgment” to solve problems.

5. CONCLUSIONS

Construction engineers are encountering and resolving various problems in their daily works. From problem-solving process, the construction engineers accumulate valuable experience and knowledge to perform construction engineering and management tasks more effectively and efficiently. Unfortunately, such valuable experience and knowledge have been stored in the minds of experienced engineers. It is generally not sharable to other junior engineers. Moreover, when experienced engineers leave or retire from the firm, their valuable knowledge is lost from the firm. Although historical lesson-learned files (LLFs) have been developed to record such knowledge, they generally documented specific scenarios of problem solving. A more generalized problem-solving model was not available for construction engineers.

The study proposed a Universal Construction Problem-solving Model (UCPM) based on TRIZ theory and 631 historical LLFs accumulated by a top ranked engineering consultant in Taiwan. The proposed UCPM is comprised a set of 11 problem classes (PCs), 5 process groups (PGs), a construction problem-solving matrix (CPSM) and a systematic procedure of problem solving. After verification results with 54 empirical cases, it is found that 57% of the PSPs suggested by UCPM were completely applicable and 39% were partially applicable, with an overall applicability of 96%.

Although the preliminary application shows profound potential of UCPM, the PSPs of UCOM should expand gradually as future cases are added due to the diversity of construction problems. Thereby it can create a more usable model that covers a more comprehensive or full range of construction engineering problems.

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INTEGRATING GREEN INNOVATION AND BIM FOR SUSTAINABLE CONSTRUCTION DESIGN

Wen-der Yu
Chung Hua University, Hsinchu, Taiwan, R.O.C., Email: wenderyu@chu.edu.tw

Chih-ming Wu
Chung Hua University, Hsinchu, Taiwan, R.O.C., Email: d09603004@chu.edu.tw

Shann-jeng Wen
Chung Hua University, Hsinchu, Taiwan, R.O.C., Email: shannjeng@itri.org.tw

Abstract

Construction industry consumes the most energy and emits the greatest part of greenhouse gas among all industries worldwide. Such a role gives the construction industry a unique opportunity to become the driving force for reducing negative impact on the environment. Many researchers from the other fields have adopted green innovation tools to generate more environment-friendly innovation alternatives for their original designs. Such methods haven't yet been widely applied in the construction industry. Moreover, the existing green innovation methods were criticized to be more conceptual than practical due to the difficulty of eco-efficiency assessment in the early development stage of the project. In this paper, a BIM-Enhanced Green Innovation Model (BEGIM) is proposed, which combines green innovation and building information modeling (BIM) techniques, to aid engineers/architects in developing sustainable building designs. The BEGIM adopts traditional TRIZ and the eco-efficiency design to generate more sustainable alternatives for buildings; then a BIM method is employed to acquire quantitative building information of the design model, so that eco-efficiency measure (e.g., CO_2 emission) can be calculated to evaluate the innovative design. A case study of public building construction project is selected to demonstrate the feasibility of the proposed BEGIM. It is concluded from case study result that the proposed BEGIM provides an effective and efficient tool for engineers/architect in developing sustainable construction design that is not only eco-efficient but also cost effective.

Keywords: green innovation, sustainable construction, greenhouse gas emission, building information modeling.

1. INTRODUCTION

Construction industry has been blamed for its high energy consumption and greenhouse gas emission, but low productivity. Statistics show that the building industry consumes 32% of energy worldwide (IEA, 2013) and emits 39% of CO_2 in USA (USGBC, 2007). However, construction industry wastes 57% (compares to 26% in this other industries) of its efforts during the product process (Teicholz, 2004). Paradoxically, the poor performance gives the construction industry a unique opportunity to become the key driving force for reducing negative environmental impacts.

Innovation has been conceived as a key factor in meeting future environmental challenges (Negny et al., 2012). The Organization for Economic Co-operation Development defined eco-innovation as "innovation that results in a reduction of environmental impact, no matter whether or not that effect is intended" (OECD, 2009). Innovators from many industries have adopted green (or eco-) innovation methods in the production processes to improve the sustainability of their products (Chen and Liu, 2003; Carillo-Hermosilla et al., 2010; Jones and Harrison, 2000). The World Business Council for Sustainable Development (WBCSD) proposed seven eco-efficiency elements (EEEs) for companies which develop eco-friendly products or processes in order to reduce environmental impacts (Desimone and Popoff, 1997), including:

A.Reduce the material intensity of its goods and services (material usage).

B. Reduce the energy intensity of its goods and services (energy consumption).

C. Reduce the dispersion of any toxic materials (toxicity generation).

D. Enhance the recyclability of its materials (material retrieval).

E. Maximize the sustainable use of renewable resources (resource renewability).

F. Extend the durability of its products (product durability).

G. Increase the service intensity of its goods and services (service intensity).

In order to improve eco-efficiency of the product or technology, the first three elements of the above should be reduced (i.e., minimization objectives) but the last four elements need to be increased (i.e., maximization objectives).

There is a broad diversity of eco-innovation approaches. Most of them were based on TRIZ (the Russian acronym for the Theory of Inventive Problem-solving) method (Altsuller, 2002). Such methods suffer in a common drawback of TRIZ, i.e., its level of abstraction (Negny et al., 2012). Although improvement strategies, such as Case-based Reasoning (CBR) and knowledge-based systems, were developed (Negny et al., 2012; Veerakamolmal and Gupta, 2002; Yang and Chen, 2011), the cost is lower level of inventiveness.

To conquer the above-mention problem, this paper proposes a TRIZ-based eco-innovation method that is integrated with the Building Information Modeling (BIM) tool. With such integration, the proposed method allows building designers and engineers to analysis the eco-efficiency of their innovative designs in the early stage of a construction project.

The rest of the paper is presented in the following manner: relevant literature on green innovation and BIM are reviewed first; a generic TRIZ-based eco-innovation method selected to implement green innovation of building design is revisited; then, a BIM enhanced green innovation model (BEGIM) is proposed and described in details; after presenting the proposed model, a real world green innovation case study on a public building of the Kokomo City, Indiana State, USA, is selected for demonstration; finally, conclusions and discussions are addressed based on the findings of the case study.

2. LITERATURE REVIEW

2.1. Green (eco-) Innovation Methods

Although the technology innovation model in construction engineering has been greatly improved, most of the proposed models focused on the improvement of operation efficiency or cost-effectiveness. Very few models emphasize on the improvement of environmental friendliness or eco-efficiency issues. There is an increasing demand for the construction industry to shift from the traditional economic perspective to more environment-conscious perspective of the technology innovation.

Green (or eco-) innovation has been defined as the innovation that results in a reduction of environmental impact (OECD, 2009). In the past decade, there have been many researchers devoted in developing systematic methods to achieve this goal. Carillo-Hermosilla et al. (2010) presented an analytical framework to explore the diversity of eco-innovations according to several key dimensions, e.g., design, user, product service and governance. Cascini et al. (2011) embedded the TRIZ inventive principles in a computer-aided innovation (CAI) system to bridge systematic invention practice with product lifecycle management. Fresner et al. (2010) applied TRIZ in cleaner production to reduce waste and emissions in industrial production activities. Chang and Chen (2004) developed a five-step procedure for eco-innovation design based on the technical contradiction of TRIZ theory associated with eco-efficiency axes. Kobayashi (2006) proposed a four-step process to improve the ratio of the “product value” compared to its “environmental impact” based on a Life Cycle Analysis. Sakao (2007) coupled TRIZ and quality function deployment (QFD) by integrating life cycle analysis to offer a more detailed analysis of eco-efficiency design factors.

Veerakamolmal and Gupta (2002), Yang and Chen (2011), Negny et al. (2012), etc., presented different combinations of TRIZ with CBR for eco-innovations. Their methods improved the over-abstraction drawback of traditional TRIZ methods by providing previous design cases. However, such method also reduced the creativity and inventiveness of innovation alternatives.

The literature analysis summarizes that TRIZ was widely adopted in eco-innovative design approach because it offers a systematic approach to generate real technological breakthroughs. However, it provides only conceptual ideas for green designs. Such a limitation may hinder its application in the construction engineering unless more realistic analyses can be conducted on the innovation alternatives in the early stage of a construction project.

2.2. Building Information Modeling (BIM)

"Building information modeling (BIM) is a digital representation of the building process to facilitate exchange and interoperability of information in digital format" (Eastman et al., 2011). In practice, BIM serves as a shared knowledge resource for the information about a facility forming a reliable basis for decisions during its life cycle. The building information model (namely "BIM model" in this paper) can develop progressively and be improved as the construction project proceeds according to the level of development (LOD) (AIA, 2008) defined by the stakeholders of the project.

Previous researchers have developed BIM tool to support the processes of constructability review (Hartmann and Fischer, 2007), site management (Chau et al., 2007), scheduling, workflow-based or location-based planning (Jongeling and Olofsson, 2007), safety planning (Zhang and Hu, 2011), or the identification and resolution of time-space conflicts (Jongeling and Olofsson, 2007). BIM applications in engineering design and analysis have also been extensively explored. For example, engineering analyses in such areas as structure (Barak et al., 2009), energy (Schluete and Thesseling, 2009), disaster prevention (Spearpoint, 2007) in design phase, construction planning (Ma et al., 2005), scheduling (Russell et al., 2009), project control (Feng et al., 2010), and safety (Chantawit et al., 2005) in construction phase.

From technology innovation viewpoint, the BIM model provides valuable building information of a design alternative, which can be used for econ-efficiency analysis in the early stage of a construction project.

3. REVISIT OF A TRIZ-BASED ECO-INNOVATION METHOD

As described in literature review, TRIZ theory has been widely adopted as a useful tool for eco-innovation. This section briefly revisits the procedure of a generic TRIZ based eco-innovation method that has been adopted by many previous researchers (Chen and Liu, 2003; Carillo-Hermosilla et al., 2010; Jones and Harrison, 2000; Negny et al., 2012).

The TRIZ method was developed in the former Soviet Union by Altshuller (2002), who had analyzed over 400,000 patents to build the contradiction table and 40 inventive principles (IPs). For using TRIZ method in innovative designs, the designer needs first to find corresponding contradictions for his problem then matches the meaning of each contradiction with two appropriate parameters from the 39 engineering parameters (EPs) defined in the TRIZ contradiction matrix (TCM). After then, the designer will find 3 to 4 most frequently used IPs for solving the innovative design problem from TCM. Finally, a recommended solution is generated based on the most appropriate IP obtained.

The above TRIZ innovation procedure is employed by innovators to deal with general technical contradictions exiting in product design. It usually focuses on efficiency and cost-effectiveness improvement of the contradiction problem. When TRIZ is applied to resolve eco-innovation problems, correlation between the EPs and the eco-efficiency measures need to be established. To meet this requirement, Chen and Liu (2003) suggested a look-up table that shows the relationships among the 39 EPs and the 7 eco-efficiency elements (EEEs) defined by WBCSD (Desimone and Popoff, 1997), see Table 1 for reference. While conducting an eco-innovation project, the designer should first identify the relevant EEEs to be improved. Then he/she can use Table 1 to identify the corresponding EPs according to their relevance with the EEEs. Next, the TRIZ contradiction matrix (TCM) is consulted to find the feasible IPs that further suggests the candidate design alternatives. The design alternative is considered ideally eco-efficient if it satisfies all EEEs. In a real world design task, it usually does not satisfy all elements but only some specific ones.

TRIZ EPs		WBCSD eco-efficiency elements						
		A Material reduction	B Energy reduction	C Toxicity reduction	D Material retrieval	E Resource sustainability	F Product durability	G Product service
1	Weight of moving object	◎	◎					
2	Weight of nonmoving object	◎						
3	Length of moving object	◎	◎					
4	Length of non-moving object	◎						
5	Area of moving object	◎	◎					

Table 1: Relationships among 39 EPs and 7 EEEs (Chen and Liu, 2003)(partial)

Usually candidate IPs can be obtained if there is only one contradiction. In case there are several worsening or improving parameters or some engineering parameters that cannot be determined to be worsening or improving, statistic techniques can assist designers to acquire the most favorable IPs. Two situations may be encountered while the above-mentioned "multi-contradiction" happens: (1) several worsening parameters and improving ones conflict in the design project (that means some clear and definite contradictions appear), the IPs can be found through each contradiction and then choose the most favorable ones according to the higher appearance frequency; (2) the EPs cannot be determined clearly ("multi-parameter") as worsening or improving, they would be regarded as worsening and improving parameters at the same time. Liu and Chen (2001) further suggested a look-up table of the most favorable IPs based on the occurrence frequency statistics of single EP, see Table 2. They called it "single EP inventive principles".

TRIZ EPs		Frequency of IP occurrence						
		I	II	III	IV	V	VI	VII
		>19	16~18	13~15	10~12	7~9	4~6	1~3
1	Weight of moving object	35		28	26,18,02,80,10, 15,40,29,31	27,34,01,36,19, 06,37,38	03,32,22,24, 39, 05,13,11	12,21,20,17,.04 ,30, 16,14,25,23
2	Weight of nonmoving object	35	28,10,19,01, 26	26	27, 13,02, 18	06,15,22,29	39,32,09,14, 40, 05,08,03	17,25,30,20,16, 11, 36,37,24
3	Length of moving object	01,29	15	35,04,17	10,28,08,14	19,24,13,26	16,02,34,09, 07	37,39,18,32,36, 05,12.22.25.23. 40.06, 38
4	Length of non-moving object			35	28,14,26,01,10	07,15	03,02,29,18, 30, 24,3216	17,40,08,13,27, 09, 37,38, 39,06,25,23, 19,31,12,11,05

Table 2: IP occurrence frequency statistics based on single EP (Liu and Chen, 2001)(partial)

A five-step TRIZ-based generic eco-innovation method is then proposed: (1) Identify the elements of eco-efficiency to be improved in the engineering design; (2) Look-up Table 1 to determine the relevant EPs for the identified eco-efficiency elements; (3) Find candidate IPs from Table 2 using single EP inventive principles; (4) Determine the most appropriate IPs for implementation; (5) Propose green design alternative.

4. PROPOSED BIM ENHANCED GREEN INNOVATION MODEL

The TRIZ-based eco-innovation method described in the previous section suffers in the over-abstraction problem. The innovator can only assess the feasibility of the proposed innovative alternative qualitatively, instead of quantitatively. Such a limitation makes eco-innovation method less appealing for construction industry, since any construction project involves huge capital investment. The project stakeholders tends to be more conservative in adopting innovative design alternatives unless a persuasive evidence can be provided based on concrete assessment before the design alternative is implemented.

In order to break the above limitation, this research adopts BIM technique to integrate with the eco-innovation process so that the required building information for eco-efficiency analysis of the green design alternatives can be provided. A BIM-enhanced green innovation model (BEGIM) is developed to implement the proposed idea. The procedure for the proposed BEGIM is shown in Figure 1.

The proposed BEGIM consists of 11 steps: (1) Select target—select a target building project for eco-innovation; (2) Build BIM model—build the BIM model for the target project and extract quantity take-offs of relevant materials, i.e., bill of materials (BOM); (3) Define scope—define appropriate scope of the design project for conducting eco-innovation; (4) Function modeling—build the function model of the design and identify all engineering parameters (EPs) and eco-efficiency elements (EEEs) in the design; (5) Pick relevant EPs & EEEs—consider CO_2 emission parameters to relevant EPs & EEEs in the design; (6) Single EP inventive principles—apply single EP inventive principles to find applicable IPs; (7) Candidate green design alternatives—select the most appropriate IP for implementation; (8) Build BIM model for green design alternative—build the BIM model for the selected green design alternative; (9) Extract BOM for green design alternative—extract BOM from the BIM model of the green design alternative; (10) Eco-efficiency analysis—calculate eco-efficiency measures such as CO_2 emission based on the parameters extracted from BOM; (11) Present design alternative—present the green design model to interested project stakeholders.

In order to measure the eco-efficiency of the green design alternative, a quantitative eco-efficiency index (EEI) is defined in Equation 1.

$$EEI = \frac{\sum_{i=1}^{4} MaxF_i}{\sum_{j=1}^{3} MinF_j}, \qquad (1)$$

where EEI represents the unit-free index to measure the eco-efficiency of the innovative design; *MaxF*$_i$ represents the ith maximization (environment-friendly) factors, e.g., material retrieval, resource renewability, product durability, and service intensity; *MinF*$_j$ represents the jth minimization (environment-unfriendly) factors, e.g., material usage, energy consumption, toxicity generation.

The EEI is employed for comparison of the eco-efficiency of the green vs. the base design alternatives. For simplicity, the value of all factors in the base alternative is assumed to be "1", so that the EEI of the base design is calculated to be $\frac{4}{3} = 1.33$. For the green design alternative, if the MaxF of the green innovation design alternative is better than the base alternative, it is assumed to be "2"; otherwise, it is assumed to be "0.5". Similarly, if the MinF of the green design alternative is better than the base alternative, it is assumed to be "0.5"; otherwise, it is assumed to be "2". As a result, a green design alternative that is superior in all seven EEEs will have an EEI=$\frac{2+2+2+2}{0.5+0.5+0.5} = \frac{8}{1.5} = 5.33$. With such a green innovation design, the EEI will be improved by $\frac{5.33}{1.33} = 4$ times.

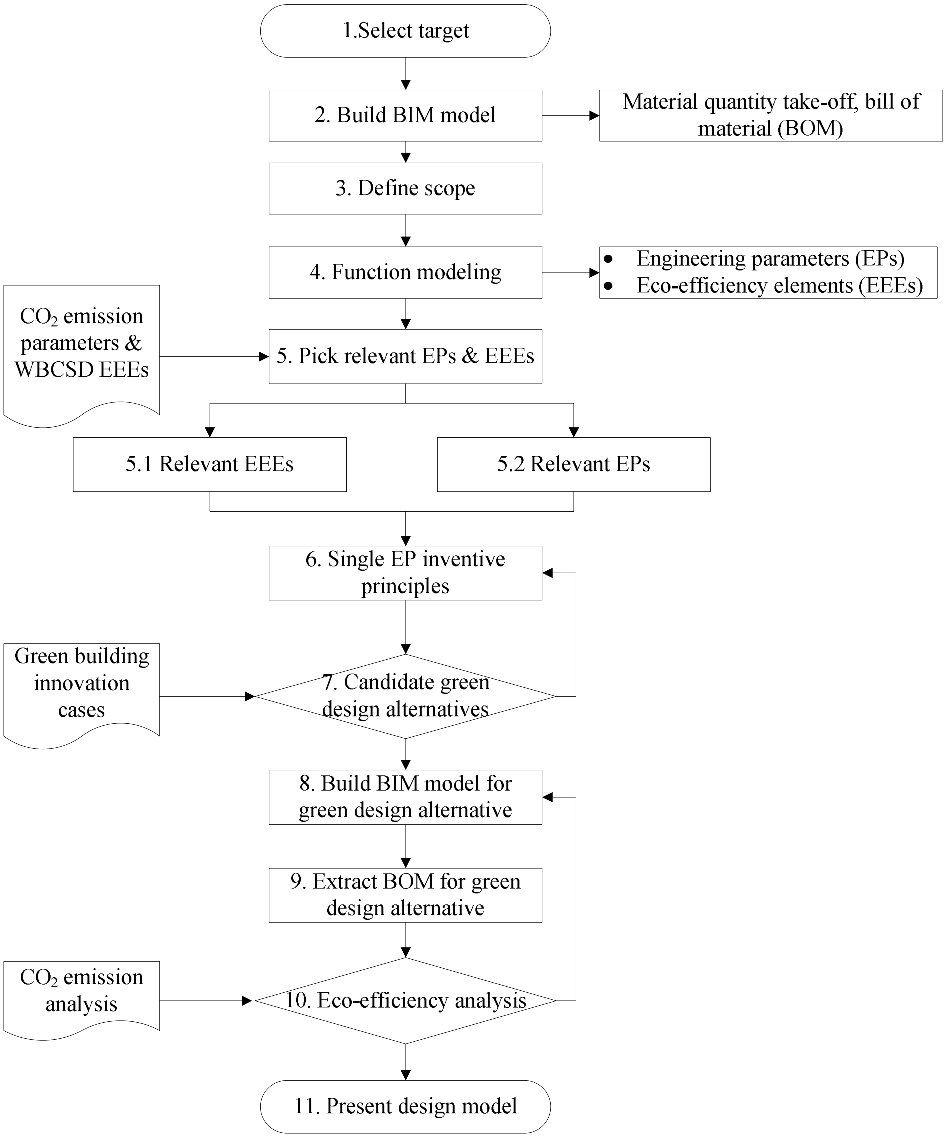

Figure 1: Procedure of BIM-enhanced green innovation model (BEGIM)

5. APPLICATION DEMONSTRATION

5.1. Selected Case

In order to demonstrate the applicability of the proposed BEGIM model for a sustainable construction design, a real world public building project is selected for case study. The selected building is the Fire Station No. 2, located at 508 E. Center Rd of Kokomo City in Indiana State, USA. The building was finished in August, 2011. Total budget is $USD 150 million. The construction period lasted for 10 months. Some pictures of the building are shown in Figure 2.

Figure 2: Pictures of the selected building

5.2. BIM Model

The BIM model of the original design (base alternative) was built. All material and geometric parameters are defined in the BIM model. With BIM, the list of structural elements and the bill of materials can be extracted if needed. Table 3 and Table 4 show the list of structural elements and BOM, respectively, for the base alternative.

Element	Wall	Floor	Foundation	Roof	Beam	Column	Total
Volume (m^3)	280.4	198.66	170.74	131.42	4.064	1.18	786.46
%	35.65	25.26	21.71	16.71	0.52	0.15	100

Table 3: Major structural elements and their volumes (base alternative)

Material type	Steel	Concrete	CMU	Brick	RIB	Roof materials	others	Total
Volume (m^3)	68.643	337.96	150.62	53.98	53.21	10.64	111.41	786.46
%	9%	43%	19%	7%	7%	1%	14%	100%

Table 4: Bill of materials (BOM) and their volumes (base alternative)

5.3. Define Scope

It is impractical to conduct eco-innovation for all elements in the building at the same time. In the demonstrated case, we selected the garage roof (total area = 348m^2) as the target for eco-innovation since roof structural is closely related to energy consumption of the building. The scope for eco-innovation in the case is to reduce the CO_2 emission of the garage roof construction for the base alternative. The CO_2 emission is relevant to WBSCD's EEI-B (energy consumption). With the help of BIM, material quantities can be extracted instantly. The CO_2 emission factors were referred to the published reports and databases (Wen, 2013; BSI, 2011; EPA, 2013). After calculation, the CO2 emissions of all elements for garage roof are listed in Table 5. It can be viewed that the total CO2 emission is 227.4 tons.

Material	Unit	Quantity	CO_2 emission (production) (kg)	Total (ton)
Formed Steel	Ton	208.18	940.86	195.868
*RIB	Ton	23.42	1194.22	27.969
**EPDM membrane	Ton	4.06	878.21	3.565
Total CO_2 emission				227.402

* RIB: Rigid insulation board; * EPDM: ethylene propylene diene monomer.

Table 5: CO_2 emissions of roof material (base design alternative)

5.4. Function modeling

In order to identify the relevant EPs of the base design alternative, a function model (primarily from energy consumption perspective) is built, as shown in Figure 3.

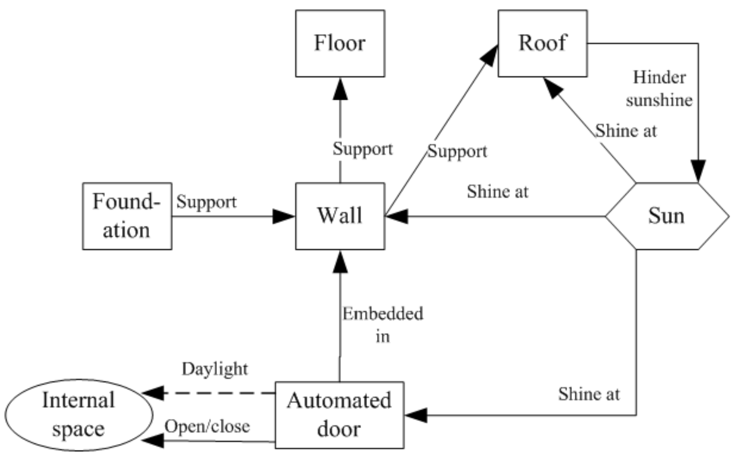

Figure 3: Function model of roof in base design

5.5. Relevant EPs and EEEs

The function model of Figure 3 depicts the interactions among different internal and external elements of the garage roof structure. For example, the primary function of roof is to hinder sun shining for heat isolation from energy consumption viewpoint. In the base alternative, an automated door system was adopted. No skylight was installed and resulted in the additional lighting requirement for the garage. The identified influential engineering parameters of the roof system are shown in Table 6. Then, the relevant eco-efficiency elements are also identified. It’s found that all EPs are related to EEE-B (energy reduction).

	Engineering parameter	Relevant eco-efficiency element
Internal space	EP-17 temperature, EP-18 brightness	17-B、18-B
Roof	EP-17 temperature, EP-18 brightness, EP-22 energy loss	17-B、18-B、22-B

Table 6: Relevant EPs and EEEs (base design alternative)

5.6. Application of Single EP Inventive Principles

Applying Single EP Inventive Principles (refer to Table 2), the “multi-parameter” (EP-17, 18, and 22) situation is encountered. According to Chen and Liu (2003), four priority IPs recommended are identified: (1) IP-19 (26 times)—“Periodic action”; (2) IP-35 (22 times)—“Transformation of the physical and chemical states of an object, parameter change, changing properties”;(3) IP-32 (15 times)—“Changing color or optical properties”; and (4) IP-2 (14 times)—“Extraction, separation, removal, segregation”.

Analyzing the four candidate IPs, it is reasoned that IP-35 suggests to reduce CO_2 emission by replacing the roof materials and IP-32 suggests changing transparency of roof material to utilize daylight. As a result, a green design alternative is developed and shown in Table 7.

IP	IP description	Possible green design concepts
IP-35	● Change state, density, flexibility or temperature of object.	● Replace roof material with low CO_2 emitted materials.
IP-32	● Change color of object or surroundings. ● Change transparency of object or surroundings. ● Use additive to visualize the invisible process. ● Use color additive or fluorescence.	● Replace roof material with low CO_2 emitted and high transparent materials to increase the daylight of internal space.

Table 7: Results of single EP inventive principles

5.7. Candidate Green Design Alternatives

Two candidate green design alternatives are proposed based on the results of single EP inventive principles: (1) Aluminum roofing system—replacing steel with alumina roofing system instead of RIB roof material; (2) Aluminum and reinforced glass roofing system—Use aluminum frame system with reinforced glass roof material. Both design alternatives can reduce CO_2 emissions since either aluminum or glass is lower CO_2-emitted materials, compared with steel and RIB.

5.8. Build BIM Models for Green Deign Alternatives

In order to evaluate the eco-efficiency index (EEI) of the green deign alternatives, the BIM models of the both alternatives are built, as shown in Figure 4.

Green deign alternative I—Aluminum roofing system	Green deign alternative II—Aluminum and reinforced glass roofing system

Figure 4: BIM models of the two green deign alternatives

5.9. Extract BOM for Green Deign Alternatives

Thanks to BIM models, the required material quantities for CO_2 emission calculation can be directly extracted from the models. Table 8 and 9 shows the CO_2 emission calculations for the two green deign alternatives.

Max. wind pressure (kg/m^2)	Prod. CO_2 emission (kg)	CO_2 emission for aluminum (kg)	CO_2 emission for hardware parts (kg)	Total CO_2 emission (Ton)
0	73.3	25508.4	1622.87	27.131
1	78.26	27234.48		28.857
2	83.22	28960.56		30.583
3	88.18	30686.64		32.309
4	93.14	32412.72		34.035
5	98.1	34138.8		35.761

Table 8: CO_2 emission calculation for aluminum roofing system

Max. wind pressure (kg/m^2)	Prod. CO_2 emission (kg)	CO_2 emission for aluminum (kg)	CO_2 emission for hardware parts (kg)	Total CO_2 emission (Ton)
0	17298.8	6874.56	1622.87	25.796
1	18469.36	7549.92		27.642
2	19639.92	8225.28		29.488
3	20810.48	8900.64		31.333
4	21981.04	9576.00		33.179
5	23151.6	10251.36		35.025

Table 9: CO_2 emission calculation for aluminum and reinforced glass roofing system

5.10. Eco-efficiency Analysis

It can be obtained that the maximum CO_2 emission for Alternative I is 37.4 tons (considering highest wind pressure) and 36.7 tons for Alternative II. The total CO_2 emission for either alternative is much lower than that of the base design alternative (i.e., 227.4 tons). Adopting Equation (1), assume that all other EEEs remain the same except that EEE-B is improved. Considering EEE-B value as "1" for the base design alternative, it is improved to be $\frac{37.4}{227.4} = 0.164$ for Alternative I and be $\frac{36.7}{227.4} = 0.161$ for Alternative II. As a result, the EEIs of Base Alternative, Alternative I, and Alternative II are calculated as follows:

$$EEI_{Base} : EEI_I : EEI_{II} = \frac{4}{3} : \frac{4}{2.164} : \frac{4}{2.161} = 1.33 : 1.85 : 1.85 \cong 1 : 1.39 : 1.39 \,, \qquad (2)$$

where EEI_{Base} represents the EEI value of Base Alternative, EEI_I is the EEI value of Alternative I, and EEI_{II} is the EEI of Alternative II.

It's obvious that both Alternative I and II are more eco-efficient than the Base Alternative in terms of EEI measure. The improvement is nearly 40% for both alternatives. Therefore both alternatives pass eco-efficiency review. Although the energy consumption for the operation and maintenance phase is not included in the demonstration case, it is intuitive that Alternative II utilizes daylight for indoor lighting so that the electric consumption will be reduced during operation. Even though daylight will also increase indoor temperature during summer time, it won't actually increase energy consumption since there is no air conditioning requirement in the garage space. As a result, Alternative II is recommended to be the green design alternative for the garage roof of the selected case.

5.11. Design Model Presentation

Finally, the proposed green design alternative is presented to project stakeholders as the result for green innovation. Some pictures of the recommended green design alternative are shown in Figure 5. The cost analysis of the base and green design alternatives are shown in Table 10. It is found that the recommended alternative is not only more eco-efficient, but also more cost-effective. Cost effectiveness is improved by 20.3%.

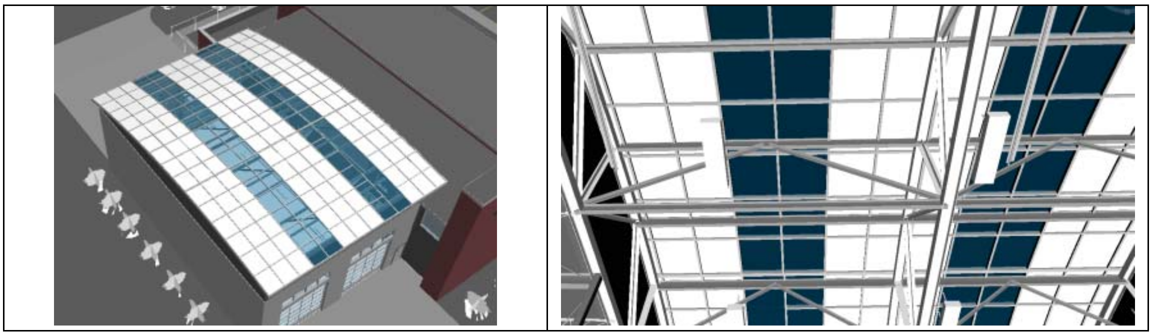

Figure 5: Recommended green design alternative

	Material	Unit	Quantity	Unit price	Item cost	Total cost (USD)
Base Alternative	RIB	M^3	22.1	96.00	2121.6	26945.6
	EPDM membrane	m^2	348	20.00	6960.0	
	Formed Steel	*Tsai	3828	4.67	17864.0	
Green Design Alternative	Aluminum	*Tsai	2593.4	5.17	13399.2	21480.4
	Reinforced Glass	*Tsai	1234.6	4.67	5761.2	
	Hardware	m^2	348	6.67	2320.0	

*Tsai: a Taiwanese measure for area, 1 Tsai=30.3cm $\times$ 30.3cm = 918.09 cm^2= 0.0918m^2

Table 10: Cost-effectiveness comparison for the alternatives

6. CONCLUSIONS

The paper proposed a BIM-enhanced Green Innovation Model (namely BEGIM) for green innovation design of a building. Although only part (garage roof) of the building is considered for case study, the results show that green innovation method cannot only improve the eco-efficiency but also cost-effective. It also demonstrates that the integration of BIM technique and green innovation has significant potential to improve the sustainability of a construction project. Some valuable findings from the case study are summarized in the following:

1. Green innovation method such as the TRIZ-based eco-innovation method presented in the paper provides a systematic approach to improve eco-efficiency elements defined by WBCSD. It also has a potential to improve construction sustainability.

2. BIM technique offers the critical building information required for analysis of the green design alternative, so that innovative alternatives can be assessed and evaluated before implementation. In this research eco-efficiency and cost-effectiveness are analyzed. Future research can extend to other aspects such as structural, energy consumption, fire protection, etc.

3. Some desirable functions for green design are still missing in the prevailing BIM software, such as eco-efficiency analysis, function modeling, TRIZ analysis, etc. Future researchers are encouraged to pursue in this directions.

The successful preliminary results obtained from the case study have shown the potential of the proposed BEGIM for sustainable construction. There are some works needed to do before the green design alternative is implementable in practice, such as structural analysis under the environmental settings of the building location, the detailed design of construction parts, more in-depth analysis of energy consumption during operation, etc. These works will be included in the future research of the team.

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DECISION SUPPORT ANALYSIS FOR SAFETY ASSURANCE IN METRO CONSTRUCTION BASED ON FUZZY BAYESIAN NETWORKS

Limao Zhang
University of Maryland, College Park, USA, Huazhong University of Science and Technology, Wuhan, China

Xianguo Wu *
Huazhong University of Science and Technology, Wuhan, China, wxg0220@126.com

Lieyun Ding
Huazhong University of Science and Technology, Wuhan, China

Miroslaw J. Skibniewski
University of Maryland, College Park, USA, Institute of Theoretical and Applied Informatics, Polish Academy of Sciences

Hanbin Luo
Huazhong University of Science and Technology, Wuhan, China

Abstract

This paper presents a novel and systemic decision support model based on Fuzzy Bayesian Networks (FBN) for safety assurance in metro construction. An expert confidence index is proposed for the fuzzification in probability assessment of basic risk factors, aiming to ensure the reliability of collected data during the expert investigation. A fuzzy-based decision approach, with the capacity of forward reasoning, sensitivity analysis and backward reasoning, is developed based on Bayesian inference. The safety assurance progress is extended to the entire life cycle of risk-prone events, including the pre-accident, during-construction continuous and post-accident control. A typical hazard concerning the tunnel leakage in the Wuhan Yangtze Metro Tunnel construction is presented in a case study. The results demonstrate the feasibility of the proposed method and its application potential. The proposed method can be used as a decision support tool to provide guidelines for safety assurance in metro construction, and thus increase the likelihood of a successful project in a complex environment.

Keywords: decision support analysis; safety assurance; Fuzzy Bayesian Networks (FBN); metro construction; complex environments

1. INTRODUCTION

In the past ten years, metro construction has presented a powerful momentum for rapid economic development worldwide (Ding et al., 2012a; Ding et al., 2012b). Owing to various risk factors in complex environments, safety violations occur frequently in metro construction and bring enormous hidden dangers for the public safety (Zhang et al., 2013). Many safety hazards have led to the growing public concern for a priori risk assessment in relation to the metro construction safety (Ding and Zhou, 2013; Ma et al., 2013).

Risk analysis can be divided into qualitative and quantitative risk analysis. The former includes fault tree analysis (FTA), comprehensive fuzzy evaluation method and check list; while the latter includes job risk analysis method, influence diagrams, neural network, and support vector machines. These risk-based analysis methods make a significant contribution to the safety control in complex engineering projects (Piniella and Fern A Ndez-Engo, 2009), but they are confined to static control management. When associated parameters, such as geological, design and construction parameters are changed, these methods cannot accurately illustrate the updated features in dynamic environments as the construction progress evolves. Nor can the professional supports or suggestions be provided in real time. Recently, Bayesian Networks (BN) has been proposed to model the complexity in the man–machine system. It can describe the dependencies between variables both qualitatively and quantitatively, and is widely used to implement uncertain knowledge representation and uncertainty reasoning. BN is powerful in dealing with uncertainty and widely used for risk and reliability analysis under the dynamic environments (Langseth and Portinale, 2007).

In conventional BN analysis, the occurrence probability of basic events was always regarded as a crisp value. However, in engineering practice, it is difficult or nearly impossible to obtain exact values of probability due to the lack of sufficient data (Mentes and Helvacioglu, 2011). Therefore, a group decision making method is generally employed to assess the occurrence probability of basic events. Hanss (1999) noted that the fuzzy set theory (FST) provides a successful tool to solve engineering problems with uncertain parameters. The uncertainties can then be considered in term of intervals or fuzzy numbers (Horcik, 2008). In recent research, developments and applications, FST and BN have both emerged as powerful and effective tools for reasoning under conditions of uncertainty (Eleye-Datubo et al., 2006). Thus, it is certainly quite appropriate to investigate the amalgamation of both techniques. The amalgamation of FST and BN may well prove to provide the indispensable means of incorporating human factors/elements in a probabilistic risk analysis model domain (Eleye-Datubo et al., 2008).

This paper therefore investigates the possibility of merging BN and FST to provide an alternative means to facilitate the risk analysis in metro construction. A novel and systemic decision support model based on Fuzzy Bayesian Networks (FBN) is proposed to provide guidelines for safety assurance through the entire life cycle in metro construction, including the pre-accident, during-construction continuous and post-accident control. A typical hazard concerning the tunnel leakage in the Wuhan Yangtze Metro Tunnel construction is presented in a case study. The results demonstrate the feasibility of the proposed method and its application potential.

2. FUZZY BAYESIAN NETWORKS

Fuzzy set theory (FST) was first introduced by Zadeh (1965) in order to deal with uncertainty due to imprecision and vagueness. FST provides a basis to generate powerful problem-solving techniques with wide applicability especially in the field of decision making (Chen and Chen, 2007). In general, FST uses triangular, trapezoidal and Gaussian fuzzy numbers, which convert the uncertain numbers into fuzzy numbers (Abbasbandy and Hajjari, 2010). Without loss of generality, triangular fuzzy numbers are often utilized to provide more precise descriptions and to obtain more accurate results (Li et al., 2012). Thus, in this paper, triangular fuzzy numbers are applied for representing the probabilities of basic events. A fuzzy number $\tilde{P}$=(*a*, *m*, b) is called a triangular fuzzy number where *a*, *m*, and *b* represent respectively the lower least likely value, the most likely valve, and the upper least likely value. Based on the work of Mentes and Helvacioglu (2011), assuming two triangular fuzzy numbers $\tilde{A}_1 = (a_1, m_1, b_1)$ and $\tilde{A}_2 = (a_2, m_2, b_2)$, the operators between $\tilde{A}_1$ and $\tilde{A}_2$ can be defined by Eq. (1), including addition, subtraction, multiplication, and division.

$$\begin{cases} \tilde{A}_1 \oplus \tilde{A}_2 = (a_1 + a_2,\ m_1 + m_2,\ b_1 + b_2) \\ \tilde{A}_1 \ominus \tilde{A}_2 = (a_1 - a_2,\ m_1 - m_2,\ b_1 - b_2) \\ \tilde{A}_1 \otimes \tilde{A}_2 = (a_1 a_2,\ m_1 m_2,\ b_1 b_2) \\ \tilde{A}_1 \oslash \tilde{A}_2 = (a_1/b_2,\ m_1/m_2,\ b_1/a_2) \end{cases} \tag{1}$$

During the BN construction, analysts are confronted with insufficient data concerning probabilities of root nodes. In the engineering practice, the occurrence of an extremely hazardous event is rare, and therefore, the data would be rare. In the absence of sufficient data, it is necessary to work with rough estimates of probabilities (Liu and Tsai, 2012). FST offers the frame of analysis that could deal with imprecision in input failure probabilities for the estimation of leaf root probability, and such analysis is termed Fuzzy Bayesian Network (FBN). It is essential to choose proper fuzzy probability measure to conduct fuzzy Bayesian inference. Based on the work of Halliwell et al. (2009), the Fuzzy marginalization rule, and Fuzzy Bayesian rule can be calculated by Eqs. (2) and (3), respectively. Herein, *T* stands for the leaf root, while *X* stands for the root node. Combing with Eq. (1), the inference of FBN can then be conducted.

$$P\left(T = t_j\right) = \sum_i P\left(X = x_i\right) \otimes P\left(T = t_j \middle| X = x_i\right) \tag{2}$$

$$P\left(X = x_j \middle| T = t_j\right) = \left[P\left(X = x_i\right) \otimes P\left(T = t_j \middle| X = x_i\right)\right] \oslash P\left(T = t_j\right) \tag{3}$$

3. FUZZIFICATION IN PROBABILITY ASSESSMENT

3.1 Limitations on current fuzzy probability assessment

In fuzzy based probability analysis, a group decision making method is currently employed to define the linguistic terms to assess the fuzzy probability of occurrence of basic events. There mainly exist two deficiencies during the current fuzzy probability assessment process as follows:

(1) In traditional expert investigation, all collected survey data is entered into the fault tree without any kind of data reliability evaluation. In fact, most interviewed individuals have different confidence levels for their subjective judgments according to their educational levels, working years and risk attitudes. Thus, a certain deviation exists in the data reliability among different interviewed individuals. It is therefore necessary to carry out the data reliability evaluation with expert ability and subjectivity fully considered.

(2) During the division of probability intervals, five linguistic terms [very low (VL), low (L), medium (M), high (H), and very high (VH)] are commonly used to assess the probability of occurrence. The current probability span is excessively large within a single interval. For instance, the scope of "H" ranges from 21.5% to 67% (see Abdelgawad & Fayek,(2010)). Such rough intervals division cannot meet the required precision for failure probability assessment of basic events in metro engineering practice.

3.2 Expert confidence index

Expert confidence index is proposed to reveal the reliability of the data obtained from interviews with various individuals. For one thing, the expert judgment ability needs to be first taken into account. In construction practice, it is generally considered that the judgment ability of individuals tends to become increasingly sophisticated and stable with the accrual of educational background and working experience. In other words, the judgment ability level, denoted by ζ , is improved accordingly. The judgment ability is divided into four levels, represented by "I, II, III, IV". The level "I" with a score ζ =1.0 stands for a highest reliability for the expert judgment ability. For another thing, the expert confidence index involves a kind of subjective measurements. It is necessary to collect individuals' subjectivity information related to their judgments during the expert investigation. Therefore, the subjective reliability level, denoted by ψ , is proposed to measure the experts' reliability towards their judgments by themselves. The subjectivity reliability ψ is divided into five levels with a score of "1.0, 0.9, 0.8, 0.7, 0.6", respectively. The higher the ψ , the more reliable the judgment.

Taking both the judgment ability level ζ and the subjectivity reliability level ψ into consideration, the expert confidence index, denoted by θ, is then calculated by Eq. (4). In this way, the reliability of the collected data can be secured.

$$\theta = \zeta \times \psi \tag{4}$$

3.3 Probability interval division and expert investigation

It is known that the size of the probability intervals can indicate the reliability of the estimation. Short intervals indicate that the statistic is precisely known, while wide intervals indicate uncertainty. To reach the highly required precision for the occurrence probability of the top event in the metro construction practice, it is better to conduct a group of short intervals, rather than wide intervals. However, according to Dawes' experiment, the use of 5-9 point scales was likely to produce slightly higher mean scores relative to the highest possible attainable score, and a larger number was usually impractical (Dawes, 2008). Therefore, in this research, the occurrence probability of basic events is divided into 9 intervals, represented by "1~9". The *k*th interval is defined by [a_k, a_{k+1}] together with a mean c_k ($1 \le k \le 9$). During the expert investigation, the purpose of questionnaires is to collect the information related to occurrence probability interval *K* and subjectivity reliability level ψ. For "Probability interval *K*", interviewed individuals were required to fill in a number ranging from 1 to 9. For "Subjectivity reliability level ψ", they were required to fill in a number ranging from 1.0 to 0.6. If they fail to evaluate the data reliability within a reliability degree of more than 0.6 by themselves, that field can be left blank.

3.4 Data gathering

Assuming one considers the occurrence probability of a specific basic event is in the *k*th interval with a subjective reliability ψ, the expert confidence index θ for the event lying in the *k*th interval can then be calculated by Eq. (4). In general, θ is lesser than 1, which means that the event has a residual probability of 1-θ lying in other intervals. This kind of information is often lost, regardless of the potentially useful information. According to the Gaussian distribution patterns of random variables (Montgomery et al., 2009), the occurrence probability tends to fluctuate around its expectation, and decrease gradually as it goes far away from the expectation. Thus, a simplified formula concerning the distribution of residual probability 1-θ among other intervals is presented in this paper, as seen in Eq. (5).

$$p_i = \begin{cases} \dfrac{(a_k - a_{k-i})}{\sum_{j=1}^{k-1}(a_k - a_j)} \times \dfrac{1-\theta}{2}, & 1 \le i \le k\text{-}1 \\ \theta\ , & i = k \\ \dfrac{(a_{18+k-i} - a_k)}{\sum_{j=k+1}^{17}(a_j - a_k)} \times \dfrac{1-\theta}{2}, & k+1 \le i \le 9 \end{cases} \tag{5}$$

3.5 Probability fuzzification

In an actual investigation, there are *S* experts involved in the investigation. For the purpose of data analysis and normalization processing, the average occurrence probability of a specific basic event lying in the *i*th interval is calculated to be P_i (1≤*i*≤9) using Eq. (6). According to the Gaussian distribution patterns of random variables, the data reliability for the random variable lying in the interval [E(*p*)-3σ, E(*p*)+3σ] reaches up to 99.7%,where E(*p*) stands for the expectation and σ stands for the standard deviation (Montgomery et al., 2009). The above mentioned principle is also called the "3σ rule". In this paper, the "3σ rule" is adopted for the probability fuzzification process, as seen in Eqs. (7)~(9).

$$P_i = \sum_{i=1}^{S} p_i \Big/ S \tag{6}$$

$$m = E(P) = \sum_{i=1}^{9} \left(c_i \times P_i \right) \tag{7}$$

$$\sigma = \sqrt{D(P)} = \sqrt{\sum_{i=1}^{9} \left[\left(c_i - E(P) \right)^2 \times p_i \right]} \tag{8}$$

$$a = m - 3\sigma; \quad b = m + 3\sigma \tag{9}$$

4. SAFETY ANALYSIS APPROACH BASED ON FUZZY BAYESIAN NETWORKS

Each risk event has its own life cycle, namely before, during and after the accident. Therefore, safety control of risk-prone events can be divided into three stages in the overall work process: pre-accident control, during-construction continuous control and post-accident control. Taking advantage of the powerful reasoning features within FBN model, forward reasoning, sensitivity analysis and background reasoning techniques can be employed to the safety control of above three stages, accordingly. In this way, real-time and effective support can be available for decision makers in the entire life cycle of risk-prone events.

4.1 Forward reasoning

Forward reasoning aims to predict the probability distribution of risk event (*T*) under the combination of risk factors (X_1, X_2… X_n). The state of each risk factor is treated as evidence input into the FBN model. Probability distribution of *T*, represented by *P*(*T=1*), is calculated by Eq. (10). *P*(*T=1*) can be served as indicators to evulate the risk of *T*, helping decision makers take proper preventions in advance.

$$P(T=1)=\sum_{1}^{2^n}\left[P\left(T=1 \middle| X_1=x_1,X_2=x_2,\ldots,X_n=x_n\right)\otimes P\left(X_1=x_1,X_2=x_2,\ldots,X_n=x_n\right)\right], x_i\in\{0,1\} \tag{10}$$

where, n stands for the number of the root nodes X_i. Each root node has two states, "Occur" and "Not occur", denoted by "1" and "0", respectively. Thus, n root nodes contribute to 2^n combinations.

4.2 Sensitivity analysis

Sensitivity analysis plays an important role in probabilistic safety assessment, aiming to illustrate the performance of each risk factor's contribution to the occurrence of an accident. Therefore, three key performance indicators (KPIs), *REV*, *RRV*, and *AVG*, are proposed to measure the contribution of each risk factor X_i to risk event *T.* Key risk factors can then be identified as to help engineers determine the main checkpoints in the construction stage.

REV(*Risk Expansion Value*) is used to assess the performance of risk expansion for each risk factor X_i, represented by $I^{REV}(X_i)$. *RRV* (*Risk Reduction Value*) is used to assess the performance of risk reduction for each risk factor X_i, represented by $I^{RRV}(X_i)$.*AVG* (Average Sensitivity *Measure*) is used to measure the average sensitivity of risk factor X_i, represented by $I^{AVG}(X_i)$. The higher the value of each key performances indicator (KPI), the more responsibility X_i has in risk reduction of *T.* Accordingly, theses three KPIs can be calculated by Eqs. (11)~(13), respectively. In the meantime, one KPI can be used in conjunction with the other two, and be verified by their results as well. Normally, those factors at the top of the ranking list related to each indicator are considered as the key risk factors for safety assurance in real projects.

$$I^{REV}(X_i)=\left[Max\left\{P\left(T=1 \middle| X_i=x_i\right)\right\}!\;\; P(T=1)\right]\varnothing P(T=1),\;\; x_i\in\{0,1\}, i=1,2,\ldots,n \tag{11}$$

$$I^{RRV}(X_i)=\left[P(T=1)\; - Min\left\{P\left(T=1 \middle| X_i=x_i\right)\right\}\right]\varnothing P(T=1),\;\; x_i\in\{0,1\}, i=1,2,\ldots,n \tag{12}$$

$$I^{AVG}(X_i)=\frac{1}{2}\left[I^{REV}(X_i)\oplus I^{RRV}(X_i)\right],\;\; i=1,2,\ldots,n \tag{13}$$

4.3 Backward reasoning

Compared to traditional risk-based methods, such as FTA, fuzzy comprehensive evaluation and neural networks, the feature of background reasoning technique is matchless in FBN model (Khakzad et al., 2011). Background reasoning aims to obtain the posterior probability distribution of each risk factor when an accident occurs. Posterior probability distribution could provide reliable scientific references for fault diagnosis. Posterior probability distribution of risk factor X_i, represented by $P(X_i=x_i|\ T=1)$, can be calculated by Eq. (14). X_i is more likely to become the direct cause of the accident T when $P(X_i=x_i|\ T=1)$ is close to 1.

$$P(X_i = x_i | T = 1) = \left[P(X_i = x_i) \otimes P(T = 1 \mid X_i = x_i) \right] \varnothing P(T = 1), \quad x_i \in \{0,1\}, i = 1,2,...,n \tag{14}$$

4.4 Defuzzification

In the above fuzzy based risk analysis, the calculated result for the leaf node or root node remain to be a fuzzy triangular number, denoted by $P_i=(a_i, m_i, b_i)$ (i=1,2,...,k). For the purpose of risk ranking in the Bayesian inference, it is necessary to transform fuzzy values into a crisp value at the defuzzification stage. Specifically, the defuzzification of the fuzzy number P_i is represented by the triangular center of gravity, denoted by G_i. The transformation from F_i into G_i is calculated by Eq. (15) as follows.

$$G_i = \frac{(m_i - a_i) + (b_i - a_i)}{3} + a_i, \text{ i=1,2,...,}k \tag{15}$$

5. FUZZY DECISION ANALYSIS IN METRO CONSTRUCTION – A CASE STUDY

Due to the complexities in the underground construction techniques and the surrounding environments, the waterproof work in tunnels is considered as a highly complicated project associated with large potential risks. Statistics showed that the phenomenon of water leakage existed in more than half of the existing tunnels (Jing-Pei, 2007). A case concerning the risk analysis of the tunnel leakage in the construction of Wuhan Yangtze Metro Tunnel (WYMT) is presented in this paper.

5.1 Step 1: Establishment of BN-based model

In the past seven years, our research group based at Huazhong Univ. of Science and Technology has undertaken major research initiatives in safety control systems in metro engineering, such as Shenyang Metro, Zhengzhou Metro, Shenzhen Metro and Wuhan Metro. We have also developed early warning web-based systems for safety control of each project. Based on the support of the web-based systems, large amounts of monitoring records have been accumulated along with work progress of these projects, as well as some other safety management materials. With the support of prior expert knowledge achieved from standards, technical reports, and expert experience, we first make efforts to carry out the relevant risk factors for the tunnel leakage by means of risk mechanism analysis. Also, the relevant result in previous literatures, such as the constructed fault trees, numerical simulation tests and analysis, can be used for integrating the relationships between the risk factors (root nodes) and the risk event (leaf node). Finally, the Tunnel Leakage Bayesian Network (TLBN) is established, as seen in Fig. 1.

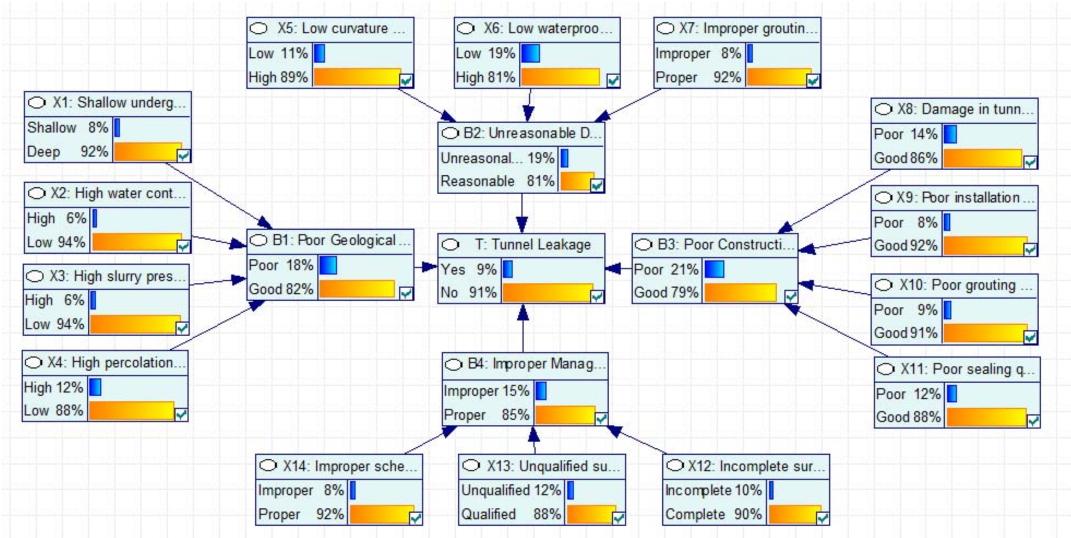

Fig. 1. Established model of TLBN in tunnel construction

5.2 Step 2: Fuzzy probability assessment

During the expert investigation, questionnaires were administered to the group of experts. The expert group consisted of 64 domain experts with at least of five years of working experience and of 42 research workers in this field. Based on their experience and knowledge, they individually evaluated the occurrence probability intervals of basic events together with their subjective reliability. The expert confidence index θ among individuals was then calculated by Eq. (4). In addition, the reliable confidence was distributed among 9 intervals using Eq. (5). Subsequently, the frequency assessment of basic events was calculated, and the results were accepted as fuzzy numbers. The probability scores obtained from the group of experts were finally converted to fuzzy failure rates using Eqs. (6)~(9). Table 1 presents the results of fuzzy probability assessment of basic events.

Table 1. Results of fuzzy probability assessment of basic events

Root Node	Fuzzy Probability	Root Node	Fuzzy Probability
X_1: Shallow underground water	(0.07, 0.08, 0.09)	X_8: Damage in tunnel segments	(0.12, 0.14, 0.16)
X_2: High water content of soil	(0.05, 0.06, 0.07)	X_9: Poor installation of tunnel segments	(0.07, 0.08, 0.09)
X_3: High slurry pressure	(0.04, 0.06, 0.08)	X_{10}: Poor grouting quality	(0.08, 0.09, 0.10)
X_4: Large percolation coefficient	(0.10, 0.12, 0.14)	X_{11}: Poor sealing quality	(0.11, 0.12, 0.13)
X_5: Low curvature of tunnel segments	(0.09, 0.11, 0.13)	X_{12}: Incomplete surveying documents	(0.08, 0.10, 0.12)
X_6: Low waterproof capability	(0.17, 0.19, 0.21)	X_{13}: Unqualified sub-contractor	(0.10, 0.12, 0.14)
X_7: Improper grouting ration	(0.07, 0.08, 0.09)	X_{14}: Improper schedule scheme	(0.07, 0.08, 0.09)

5.3 Step 3: Fuzzy-based risk analysis

WYMT, known as "the first metro tunnel across the Yangtze River in China", is an important route connecting two large cities, comprising the metropolitan area of Wuhan, namely Wuchang and Hankou. It is a double-spool tunnel with a total length of almost 6200 meters. A specific monitoring section is taken as an example to present the detailed fuzzy-based risk analysis, where the tunnel exactly passes under under the foundation of Jiangbei Levee with a height of 25.3m from the foundation base to the tunnel roof. Jiangbei Levee is a significant life line for flood control in Wuhan, affecting nearly 10 million lives. For this reason, no fault is permitted while the tunnel is crossing under the existing structure. TLBN is offered as a decision support tool for safety control, providing real-time and effective support for decision makers in the overall drilling process.

(1) Pre-accident control

Pre-accident control aims to calculate the probability distribution of the occurrence of tunnel leakage (T) before the tunnel goes through the foundation of Jiangbei Levee. Sufficient time could then be left for decision makers to optimize the proposed scheme.

In the proposal phase, decision makers do not have a deep understanding about the factual situation related to the project risks. In this situation, the prior fuzzy probability of risk factors (X_i) was first entered into TLBN as input evidence. As the output, the probability of the tunnel leakage occurrence turned out to be (0.06, 0.09, 0.11) using Eq. (12), as seen in Table 5. Then Eq. (15) was employed to transform the fuzzy probability into a crisp number which was $G(T=1)=8.90\% > 5\%$. Results indicate that the safety of the tunnel waterproof is not significantly assured. In the site selection phase, decision makers may face many possible schemes of site selection, say, three schemes denoted as A, B, and C. Then we list the geological parameters of each scheme, enter the current states (Deep, High or Low) into TLBN as evidence, and then compare the results of model output. Obviously, the results shown in Table 2 show that C turns out to be the most competitive scheme.

Table 2. Probability distribution of the occurrence of tunnel leakage (T)

Phase	Scheme	$P(T=1)$	$G(T=1)$
Proposal	Prior probability	(0.0648, 0.0882, 0.1141)	0.0890
Site Selection	A: X_1=Deep, X_2=Low, X_3=Low, X_4=High	(0.1362, 0.1599, 0.1841)	0.1601
	B: X_1=Deep, X_2=Low, X_3=High, X_4=Low	(0.2369, 0.2727, 0.3080)	0.2725
	C: X_1=Deep, X_2=Low, X_3=Low, X_4=Low	(0.0356, 0.0472, 0.0602)	0.0477

(2) During-construction continuous control

During-construction continuous control aims to determine the key risk factors which have greater impact on the occurrence of risk-prone event, and therefore pay much more attention to these checkpoints in the construction phase. At present, this work depends greatly on experts which are regarded as "rare knowledge sources" in the engineering field. Adopting the sensitivity analysis technique of FBN model, TLBN are able to identify the key construction parameters accordingly.

In the construction phase, the values related to the geological parameters are defined and then can be entered into TLBN as given evidence. Using Eq. (11) ~ (13), three key performance indicators (KPIs), *REV*, *RRV* and *AVG* of the risk factors (X_5~X_{14}) are calculated. As shown in Fig. 2, the results indicate that the ranking list of these three KPIs is approximately consistent. Meanwhile, X_{10} (Poor grouting quality), X_{11} (Poor sealing quality) and X_{12} (Incomplete surveying documents) are at the top of the ranking list concerning each indicator. It is clear that these three risk factors are remarkably sensitive to the occurrence of tunnel leakage It is therefore necessary to place more emphasis on the control measures as to ensure the rational status of these construction parameters.

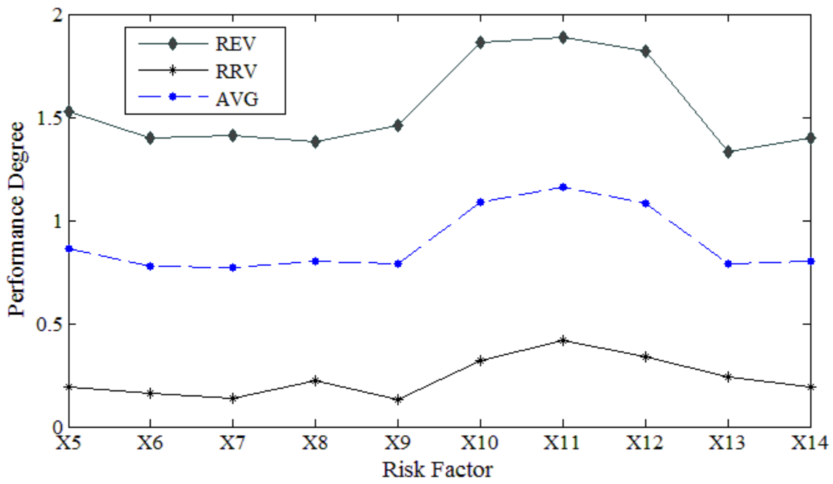

Fig.2. Ranking results of risk factor (X_i) in safety assurance of tunnel leakage

(3) Post-accident control

Post-accident control aims to identify the most likely direct cause once the accident occurs, and then carry out real-time diagnosis and proper measures. In the current situation, the most desirable action decision makers would have thought of is to invite field experts to join the expert group meetings, and then discuss to conduct the causes of the accident and propose prompt measures. This is likely to miss the critical time of problem handling, causing more serious losses. Adopting the background reasoning technique in FBN, we are able to simulate the evolution route of accidental occurrence in real time.

Using Eq. (14), the posterior probability distribution of the risk factors (X_5~X_{14}) could be calculated when the tunnel leakage occurs, as seen in Fig. 3 (a). The results indicate that X_6=Low (with a 46% chance) is most likely to be the direct cause. For this reason, the fault diagnosis would concentrate on the factor X_6, and the practical check confirms our deduction. Consequently, X_6=Low could be entered into TLBN as an extra given evidence for the subsequent background reasoning. The results as seen in Fig.3 (b) show that X_8=Poor (with a 33% chance) turns out to be the most unfavorable factor, which could be the focus of practical diagnosis for next fault diagnosis until the accident is under control. In this way, the route for the fault diagnosis in tunnel leakage can be extracted.

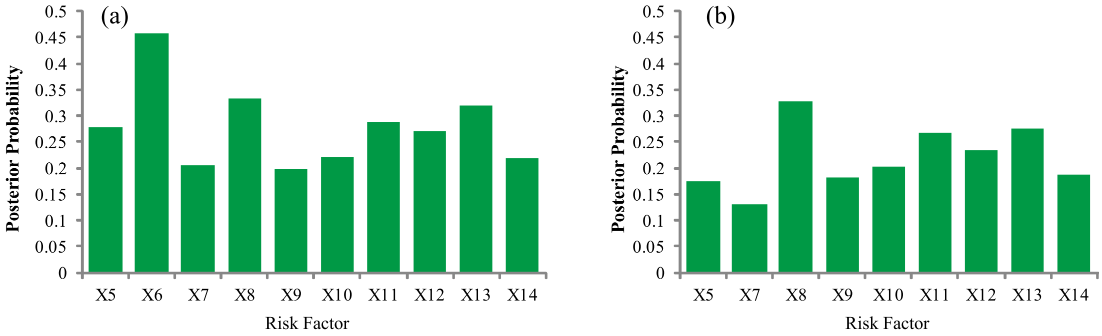

Fig.3. Fault diagnosis in tunnel leakage. (a) $P(X_i|T=1)$; (b) $P(X_i|T=1,X_6=Low)$

6. CONCLUSIONS

Metro construction is typically a highly complicated project associated with large potential risks. In recent years, safety assurance and management of metro construction have attracted broad attention due to their close relation to public safety. Due to the lack of sufficient data, it is difficult to have an exact estimation of the failure rate of the occurrence probability of undesired events. A novel and systemic decision support based on Fuzzy Bayesian Networks (FBN) for safety assurance in metro construction has been presented. A typical hazard concerning the tunnel leakage in the Wuhan Yangtze Metro Tunnel construction is used for a case study. Results demonstrate the feasibility of the proposed method, as well as its application potential.

Also, there are some other projects encountering the similar situation, where the statistical data is insufficient and high potential risks exist in complex environments, such as coal mining, dam monitoring, nuclear power plants and others. Accordingly, during the fuzzy decision analysis, there increases the need for precise failure probabilities for the purpose of safety assurance in project management practice. To reach the required high precision for the fuzzy decision analysis, the expert confidence index can be proposed to ensure the reliability of collected data during the fuzzy probability assessment, with the expert judgment ability and subjectivity being fully considered. With the capacity of forward reasoning, sensitivity analysis and backward reasoning in Bayesian inference, the safety assurance process can be extended to the entire life cycle of risk-prone events, including the pre-accident, during-construction continuous and post-accident control, accordingly. The proposed method can be used as a decision support tool to provide guidelines for safety assurance in metro construction, and it is worth popularizing in other similar projects.

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THE CHALLENGES OF GOVERNING PUBLIC PRIVATE PARTNERSHIPS IN IRAQ INFRASTRUCTURE PROJECTS

Josef Zimmermann
Technische Universität München, Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung, Munich, Germany, lbi@bv.tum.de

Omar Aljuboori
Technische Universität München, Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung, Munich, Germany, lbi@bv.tum.de

Abstract

Public-private partnership (PPP) has been used over the past 20-30 years by governments in developed countries to meet the public demand for infrastructural services. In Iraq, the PPP concept is comparatively new to the Government of Iraq (GoI), where the government has historically taken most of the responsibility for providing public services. There are few PPP projects in Iraq. However, the number is increasing. Recently the Iraqi market has experienced a number of attempts of PPP in different sectors, especially after the new investment law in 2006. The aim of this paper is to evaluate the investment environment in Iraq and to indicate the main factors affecting PPP in particular for infrastructure projects. Some literature review and data collections have been made, and for validation purposes a limited number of semi-structured interviews with professionals involved in Iraq's projects have been conducted. The findings indicate that undertaking infrastructure business in Iraq is subject to some specific risks and obstacles limiting the readiness of the private sector to participate. Finally the major issues are pointed out to be tackled by decision makers in both the public and private sectors in Iraq to establish a more efficient framework for the future PPP projects in Iraq.

Keywords: public private partnership, Risk, Iraq Infrastructure, legal system.

1. INTRODUCTION – PPPS

The shortage of infrastructure in developing countries is an important obstacle to meeting populations' demands, enterprise development and in general achieving governmental goals of progress. In order to meet such needs, encouraging private investment in infrastructure is an option that governments cannot afford to ignore.

In Germany, “PPP” is described by the Federal Ministry of Transport, Building and Urban Affairs (BMVBS) as a “long-termed, contractually regulated co-operation between the public authority and the private industry in the fulfillment of public tasks”[25]. PPP contracts thus involve private companies to various extents in the design, financing, construction, ownership and operation of a public sector task on a long term contract for up to 20-30 years [1].

According to Robert and Tiong (2010) [19], there are several commonly expected advantages in engaging in PPP likewise: (1) The possibility of the private sector help to finance infrastructure projects which governments are momentarily unable to provide, (2) an increase of quality and efficiency of public services, (3) some risk sharing and making use of the private business expertise, (4) improved revenues and reduced deficits and finally (5) the quicker achievement of markets.

Yet, the use of PPP [e.g. 8] contracts turns out to be no simple solution to governmental shortages due to their complexity. Some issues to be specifically addressed would be e.g. process transparency, the competitiveness of bids, proper risk allocation, commensurate developer returns with respect to the taken risks, selection of concession and governmental guarantees and credit advantages and finally the control over infrastructure assets [25,3].

Obviously on the governmental side, some fundamental risk issues are furthermore associated with PPP implementations due to the numerous parties involved and their complex interaction mechanisms, the higher financing and funding costs reflecting the risk taken over by the private sector [26]. Finally from a macro-economic point of view, due to the long-term character of PPP projects, the mandatory expenses and the hidden debt grow over a long period of time as a significant burden for future generations [10].

On the private investor’s side, PPP contracts differ strongly from other types of contracts. Infrastructure investment requires large up-front capital and long periods to refinance. During this time investors are exposed to severe risks with varying profiles according to the actual life-cycle phase. In addition, dealing with matters of public interest, infrastructure services tend to be politically sensitive, leading e.g. to some uncertainty regarding the assumed outcome of the project, based on e.g. toll charges [11].

According to Zimmermann [25, 27], PPP is the most comprehensive form of public-private cooperation containing all five elements Design, Build, Operate, Finance and Transfer and their complex interference. The public side defines only the requirements while the private part has all freedom to create innovative economical solutions considering the facility’s total lifecycle on the basis of a close interaction between the elements.

Yet, private companies usually access capital at fairly higher interest rates than governments due to their principally lower degree of creditworthiness. Therefore, according to Zimmermann, development, bidding and construction costs in PPP projects are in general higher in comparison to traditional public sector procurement. The advantage of a technical or functional interactive ideal solution is in urgent need to compensate for this before generating any benefit. In particular any approach of financing infrastructure projects by the use of PPP contracts is doomed to fail, just shifting expenses on an increased basis to future generations.

To the present day only very few PPP cases have been established in Iraq and been described in international publications, in particular in the infrastructure sector. On this background this investigation aims specifically at the elaboration of the specific impeding and driving issues of the PPP-investment environment in Iraq.

2. IRAQ SITUATION

2.1. Present requirements of Iraq

For the Government of Iraq (GoI) a very important task is to increase the ability to deliver not only basic services but to meet the expectations of a higher standard of living and due to the growth of population the corresponding economic growth. Appropriate responding to these needs will basically demand considerable strengthening of infrastructure [12].

In the 1980s and into the 1990s, Iraq made significant infrastructure investments. However, with few exceptions, these were poorly maintained and have been further damaged by the 2003 war and degraded by the subsequent instability. Although substantial reconstruction expenditures have been made since 2003, despite the significant development in the infrastructure sector in Iraq much still remains to be undertaken and most of the infrastructure services have not been restored to their pre-2003 levels.

The outcome of the construction industry in Iraq is still lagging behind the desired capacity to meet the requirements of the development. The Iraqi Ministry of Planning estimated the total investment required for the reconstruction of Iraq's infrastructure 2006-2010 to be about $187 billion, with a deficit in the investment amounted to $66 billion (67%). For 2010-2014 the deficit of the financing budget is expected to be about $20 billion [9].

The Iraq's economy and investment situation shows a substantial gap, signifying the urgent need for solutions which the GoI seeks to bridge by private financing in general. Attempting to contain the situation, the GoI took important steps to enable an open investment regime towards enhancing the private sector involvement by offering PPP contracts to both the benefit of the country as well as of the investing companies. In particular PPP benefits are expected to solve a major part of the investment hitch by providing alternative financial resources, additional technical and managerial expertise, innovation and knowhow thus reducing lifecycle cost, proper risk assignment, improved quality of service and performance, and enhanced public management [19].

2.2. Legal system development of PPP in Iraq

The provision of an appropriate legal framework is essential for a prospering investment environment. Therefore the GoI took pains to establish favorable laws in order to expand and improve the private sector resources for financing, construction, maintenance and operation of infrastructure and public services facility projects in Iraq.

Historically Iraq's economy has suffered from an unstable phase in the relationship between the government and the private sector, which began with decisions of nationalization of economic enterprises in 1964, weakening the private sectors investment and leaving the control to public sector companies for all the national economy. In 1967 a mixed sector emerged as a concept of partnership between public and private sectors. Law No. 103 defined in 1964 mixed sector companies as "companies that contribute to the public sector by 51% of the capital of the company". Only very little private sector investment was possible due to restricting investment rules and a virtually not existing formal *Foreign Direct Investment* (FDI).

In 1997 law No. 21 allowed for the establishment of joint stock companies where the public contributes at least 25% of the capital. It required further that any company doing business in Iraq needs to be registered with the Companies Registrar Office at the Ministry of Trade as representative office, as establishment of a subsidiary, or establishment of a branch of the parent company.

Finally Companies law No. 22 in 1997 article 15 declared that a public company shall be entitled to the right to participate in partnerships with private companies and institutions of Arab and foreign countries which led to the foundation of many joint ventures between the public and private participants.

After the 2003 war, several laws went into effect improving Iraq's business environment and changed the legal regime attracting foreign investment and allowing foreign investors national compliant treatment.

In 2005, the Ministry of Industry selected 36 public companies and factories, announced as investment opportunities for the private sector, to participate in a reorganization program. These investment opportunities were offered on the principle of partnership, where the private investors would be responsible for the reorganization, management, operation and maintenance for a limited period of 15 years. The state company would receive a share of the production profit until the end of the contract, the ownership of equipment and rehabilitation work will be transferred to the GoI at the end of the contract.

In 2006, the GoI started a new policy reform and a new investment law No. 13 [6] was issued. The new law covered all sectors of the economy with the exception of banking, insurance, oil and gas extraction and production. The basic rules and guidelines applicable to all types of investment by local and foreign private sector investors, co-operative, mixed, and public sector were defined. Investors could participate through investment in construction and operation of new projects, investment in expansion and technical upgrading of existing projects or in purchasing equity in existing projects. It included the provision of a wide range of guarantees and protection like the protection of private investors against project risks related to the GoI's responsibilities or payment obligations, political risks and market demands as well as the exemption from certain taxes.

In addition, some specific issues of permission was declared, in particular to employ non-Iraqi workers, to invest in the Iraqi stock exchange and create stock portfolios, to insure projects internationally and to open a bank account in Iraq. Due to the law projects were also protected against retroactive law amendments.

Most of these guarantees and permissions were absolutely new and induced extensive changes to the Iraqi economy by means of incoming capital and foreign experience contributing to the badly needed basic infrastructure.

The investment law No. 13 did not refer to any mechanism or model of PPP. Moreover, according to the law the right to own land was restricted only to investors of residential projects [20]. Any application of PPP models where typically a project company takes ownership of the project at least temporarily, like build-operate-transfer (BOO) or build-own-operate-transfer (BOOT) schemes were becoming impossible.

Furthermore, the law also permitted long-term leases, restricting to fifty (50) years, for the purpose of carrying out projects that have been granted an investment. Thus other project models like build-lease-operate-transfer (BLOT) and build-transfer-operate (BTO) became more promising:

In a (BLOT) scheme, the private company organization would design, finance and build a facility on leased public land. The private organization would operate the facility for the duration of the lease and then transfer ownership to the public organization. The lease would be registered with the local land registration authorities to provide public notice and gain more certainty concerning validity and enforceability. E.g. this scheme is applied at the north of Iraq since 2006, for a 1000 MW power plant project. GoI leased the real estate to the private company as a long-term agreement (according to the investment law). The private company builds, operates, finances and maintains the power plant for the specified and then transfers ownership to the GoI. With the help of this project the local government raised the electrical power supply hours from 8 hours to 23 hours per day. This equates 14% of the current Iraqi network and 36% of the electrical power needs of the northern region.

A (BTO) scheme may be required for projects that Iraqi public authorities deem to be too important to the national interest to be leased to private contractors, where infrastructure projects are typical candidates. In such case, a (BTO) scheme would allow the project to be transferred to the public authority upon its completion, and then operated pursuant to a management agreement. This scheme is not applied in Iraq yet.

Recently in 2012, the GoI is focusing on further improvement of the situation by considering a new law for PPP [23] to support the investment law and to establish a favorable legal framework. This law is at the draft stage now.

It is supposed to include explicit regulations on foreign investment, bankruptcy, PPP, labor, competition, consumer protection, securities, property rights and land registration as well as banking and tax systems. This law would newly provide the GoI's support and guarantees to a PPP project, including land acquisition support, the use of infrastructure facilities, the purchasing of the product or the services generated by the PPP project. Furthermore some issues of risk-sharing with GoI are going to be defined, e.g. against political risks, demand risks, currency risk and the extension of public loans to the private. The Policy Board would become the government agency in charge of PPP projects.

Yet the establishment of the PPP law would pass significant administrative power to the government officials. The newly established Policy Board will pool the entire PPP topics. The main responsibility of the Policy Board would be to approve, reject or send back for reconsideration PPP project proposals, develop standard documents, procedures and guidelines for the efficient implementation of the PPP, evaluate the impact of PPP proposals, review and analyze the budgetary implications of all requests for government support.

2.3. Capital markets of Iraq

In recent years, Iraq has seen significant improvements in security and economic growth, the Iraqi economic policy has focused on opening markets and fostering a business-friendly environment to attract private investment and facilitate trade. The GoI intends to involve foreign and national private investors. Plans are elaborated to rebuild the country's infrastructure, including major infrastructure projects, with a total budget of $150 billion by 2025, in addition to the budgetary funds [12].

In 2010, after the new investment law was passed the private finances including PPP contracts in some major infrastructure and residential projects were estimated over $40 billion in all sectors [24] (see figure 1). Since 2009 Iraq has attracted investments worth $23 billion [16 p.10].

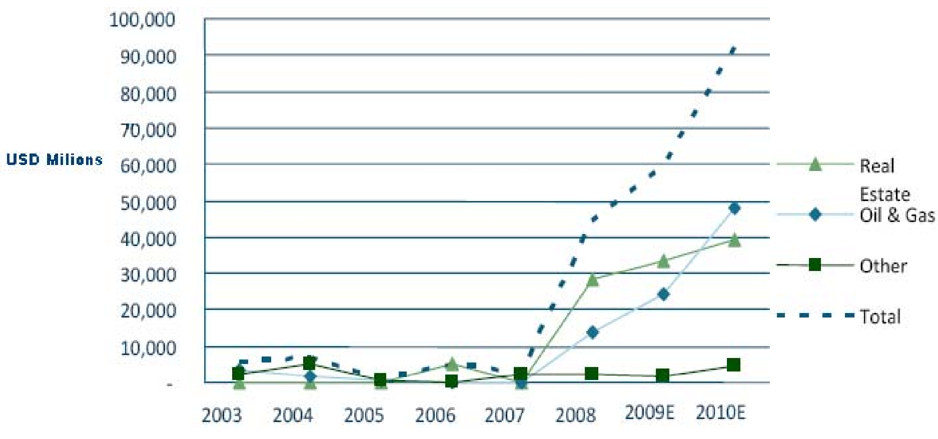

Figure 1: Investment in Iraq by sector [16 p.11]

In 2010, with the very high demand for housing in Iraq, GoI developed a five-year plan (2010-2014) targeting an economic growth rate of 9.4 % per year. The plan points out an estimated requirement of a fixed infrastructure investment of $186 billion including $86 billion of private participation [13 p.30], aiming to develop programs for economic, financial and administrative reforms, based on establishing an effective partnership between the GoI and the private sector. GoI intends therewith to build in total one million new residential units plus the entire infrastructure all over Iraq's 18 governorates. In particular the GoI expects and explicitly mentions in the strategic plan to establish these projects as build-operate-transfer (BOT), build-operate-own (BOO) and build-operate-own-transfer (BOOT) contracts [13 p.27]. Responsibilities of design, construction, management and financing are being largely passed onto the private sector. Clearly PPP projects are used as a way to achieve infrastructure projects without straining the public finance. The balance would be to entitle investors to acquire land without initial down payment, alternatively to transfer land in exchange for a share of future revenue. GoI may also provide revenue guarantees or long term loans from the TBI bank. In order to accomplish this plan, many construction projects like huge residential complexes and the according infrastructure services have been initiated. Another plan of GoI which aims at reconstruction and renovation of the existing inefficient infrastructure supports this development. The increase of investment values over the last years and the foreign investment share indicate a healthy market in Iraq as a precondition to applying successfully PPP contracts.

Meanwhile, the Ministry of Electricity confirmed in 2010 that the government is considering PPP contracts for new power plants of 6200 MW for a yearly amount of $4.5 billion.

Yet the World Bank 2012 report [21], covering the 183 economies of 183 countries all over the world ranked Iraq on position 166 of 183 countries regarding the “ease of doing business” and thus still indicates a very serious situation.

Up to now data of Iraqi organizations involved in PPP projects are rare due to the limited readiness of the Iraqi market for this type of procurement. Currently no more than five PPP projects are active of which three were accessible. In these BOOT contracts, the private companies are responsible for design, construction and financing of the projects including the required infrastructure according to the GoI demands. They own the projects’ real estate and operate and maintain the facilities for a specified period of time. GoI provides the real estate without initial down payment and is in turn obtaining a specified share of the built units and the provision of infrastructure after completion. As a guarantee for the annual payment GoI facilitates the sale of the residential units to the Iraqi people. GoI assumes several roles in this partnership e.g. by providing an operative environment for the private developer, by balancing market incentives and community interests, by assisting in project completion and by reducing the development risk via some guarantees.

3. THE PERCEIVED OBSTACLES OF PPP IN THE IRAQI INFRASTRUCTURE

Iraq is a developing country where laws, regulations and the business environment in general make certain risks particularly relevant in comparison to other countries under different conditions.

3.1. Government agencies issues

- Administrative barriers are somewhat obstructive due to high transaction costs and the delay in obtaining a planning permission or other required local authorities environmental and land approvals. The complex web of government agencies and departments can be an extremely time consuming process, delaying entire projects and affecting their financial viability [14]. The approval processes e.g. for the Delhi expressway project were responsible for 3 years delay in obtaining the concessionaire. More than fifteen government agencies were involved in the development of this highway and had to grant approvals.

Starting a project in Iraq requires in average 11 procedures, takes 77 days, costs about 116% of income per capita and requires paid-in minimum capital of over 35% of income per capita [21]. For comparison in the United Arab Emirates starting a project requires 7 procedures, takes 13 days, costs 5.6% of income per capita and requires no minimum paid-in capital.

- There is no sufficient experience available at the local authorities to support new business arrangement types. Yet there are attempts to improve the Iraqi knowledge in PPP made by the World Bank and the United Nations Industrial Development Organization UNDO offering workshops to review other countries experiences.
- GoI staffs who are involved in decision making of procurement are still “in the process of learning”. Yet the evaluations depend solely on the opinion of the national investment commission (NIC) and the related ministry, who mostly don’t have the required technical experience in particular required for complex contracts like PPP [7].
- After the political changes in 2003 the GoI policy changed from the centrally-guided economy to a market economy. A new legal system and new laws were adopted to encourage private investment. Iraq is expected by international agencies e.g. like the World Bank to continue its economic reform policies. Many of the laws and reforms are new or experimental and are expected to be refined or changed. This leads to a factor of risk playing a major role in Iraq.

3.2. Financial and banking issues

- Public institutions are dominating the banking sector. It is estimated that the 3 largest state banks, Rafidain, Rasheed and TBI, are controlling approximately 90% of all Iraqi banking assets and deposits [18]. An existing large number of private banks are only of limited use, since the contribution of private banks to a credit may legally not exceed 22.5%, while the government banks are still responsible for granting 77.5% [2]. According to the Ministry of Finance's decision No. 402 at 15/1/2009, “government agencies and state owned enterprises are not allowed to do business or place deposits with private banks”. Furthermore, according to the Ministry of Finance, the permission to grant credits for foreign companies operating in Iraq is restricted to the public bank TBI [15]. Consequently private banks are to a high degree not available for PPP projects.

- Transferring funds directly to public banks still is an unsettled process due to the lack of modern banking systems. Internal networks between branches of banks and electronic communication systems of the central bank' payment systems are only under development and therefore slowing processes down. According to the deputy governor of the Iraqi Central Bank the biggest weakness of the state banks is the lack of an internal network and the difficulty in electronic settlement of checks due to the lack of a modern electronic communication payment system at the Central Bank [4].

Currently, Iraq is developing the public banking system in cooperation with the International Monetary Fund and the World Bank by improving the banking laws, electronic banking systems, the domestic payments systems, additionally offering courses to raise the efficiency of work of the banking staff.

- Private Banks show poor flexibility in the prevailing structure of financing, granting mainly short term trades and only limited medium term loans required for real estate purposes. Before 2003 Iraqi private banks granted long term loans for many projects. The war and the regime change in 2003 led to the loss of most of these loans and thus accumulating up to 58 billion Iraqi dinars. Moreover the weakness of the bond market of the long-term deposits as well as the capital weakness and the repercussions of the global financial crisis [5] impede future long term loans.
- As the new investment law only allows foreign insurance companies in Iraq but not to invest in the insurance sector of Iraq, the private insurance market turns out to be of small size in comparison to the public side. The total aggregate annual amount of gross written premium for the 18 privately owned insurance companies in Iraq are $60 – $80 million, while the three public owned insurance companies [18] value four or five times of that. They are dominating since almost all government contracts for insurance services are awarded to the public owned insurance companies, although, article 81 in the Insurance Business Regulation Law 2005 requires that "government contract for insurance shall be procured through a public tender where all licensed insurance companies are allowed to participate".

3.3. Market issues

- The private parties need to employ experienced staff to do the technical work of the project. According to the investment law a private partner in a PPP project is forced to employ at least 50% local workers, which mostly lack the necessary experience and knowledge.
- The weakness of the Transportation systems in Iraq is mainly its unreliability leading to high transportation cost.
- The exchange rate of the Iraqi dinar is fairly unstable due to the varying monetary policy.
- Land acquisition is considered the biggest obstacle in Iraq as such is in no way supported by the legal frame work. According to the investment law the right to own land is restricted to only residential projects**.** Furthermore the law permits long-term leases not to exceed fifty years.

- Many licensed projects at both the provincial and national levels suffer from confusion about land use, due to questions of authority between involved ministries. This happened e.g. at the Karbala International Airport project, where problems between the ministries of oil, transport and electricity on the ownership of the project's land delayed the construction of the project significantly. The Oil Ministry owned most of the land because of the huge oil and gas deposits, but the Electricity Ministry planned to erect a power plant on this real estate. The situation had been developed so far that the transfer of the project to another site was considered, where the redesign amounted to approximately $ 40 million.

3.4. Legal system and laws issues

- Article 23 of the Iraqi constitution contains the following standard for expropriation: "Expropriation is not permissible except for the purposes of public benefit in return for just compensation, and this shall be regulated by law" [22]. Moreover, the investment law does not contain sufficient guarantees to protect projects from nationalization, especially using the term "an exception in guarantees" in the third paragraph of article 12 of the investment law "Non-seizure or nationalization of the investment project covered by the provisions of this law in whole or in part, except for projects on which a final judicial judgment was issued" [6, art. 12], giving the Iraqi judiciary the right to freely decide for confiscation and nationalization.
- However security is considered the most important issue for PPP in Iraq, the investment law does not refer to any clear security guarantees for PPP projects.
- The process of obtaining a PPP license according to the investment law [17 p. 6] shows that no competition exists in the tender process as only one bidder submits a tender for a project.
- To date in Iraqi law no government guidelines are given regulating the ex-ante or ex-post evaluation of a PPP project, or any concerning risk allocation as are available in other countries e.g. Germany, Australia and United Kingdom.
- To date, there is no promising PPP law to serve as a fundament for PPP contracts between the public and the private sectors. A law of PPP exists but is not passed until now (see sec. 'legal system development of PPP in Iraq'). Therefore, specific schemes have to be submitted by the government to the legislative council for approval.
- Despite the tax exemption granted in the investment law, there are a numerous fees and taxes imposed by the Iraqi laws such as: the income tax and machines tax in the Tax law No. 113 of 1982, sales tax law No. 36 of 1997, the income tax of the capital in the company law No. 21 of 1997, rent of real estate tax law No. 162 of 1959, real estate transfer tax law No. 120 of 2002, real estate tax law No. 26 of 1962, reconstruction tax law No. 38, the customs tariff law No. 23 of 1984.

For a specific project this sums up to 13 taxes per year, takes 312 days a year, paying taxes amounting to 14.9% of profit and a total tax rate 28.4% of profit. In comparison the United Arab Emirates, have 14 taxes per year, needing 12 hours a year, paying a total tax rate 14.1%

[21]. Globally, United Arab Emirates is ranked 7 of 183 economies on the ease of paying taxes.

- Finally the stark notification and reporting requirements made in the investment law No. 13, article 14 paragraph 7 could be an obstacle for the potential investors [6]. Many delays may be due to the external factors, which are generated outside the project and in many cases are not controllable factors, yet might lead to a loss of licence.

4. CONCLUSIONS

Obviously GoI takes PPP contracts as a solution to meet the budget deficit and provide the required infrastructure services. Legally as well as politically and operatively PPP is still at a very early stage of development in Iraq and thus applied on very few projects. Yet the decision to engage the private sector in infrastructure services is pushed forward by the current political agenda. Thus certain opportunities arise as exceptions and guarantees are made for private investors in the investment law No. 13 of 2006. However Iraq is still struggling taking steps into the PPP market due to a wide range of inhibiting factors. It is obvious that undertaking infrastructure business on the basis of PPP contracts in Iraq implicate many unsolved issues.

A set of major obstacles relating to the adoption of PPP in Iraq have been pointed out in this study, focusing on government agencies handling and politics, financial and banking issues, market situation and subjects of the legal system. GoI is impressively working on resolving obstacles faced by the current PPP projects but this will take time and seems to be in progress.

However, it needs to be clear that the regular payment of PPP contracts are hidden cost on the government budget which will show up sooner or later and therefore PPP is not a financing option on its own. In order to determine long term schedules it is important to review and make use of experiences from previous and current projects in other countries.

Regarding the banking and insurance issues, GoI is taking steps to develop systems, as well as start supporting private banks. Meanwhile GoI allows private banks to grant credits for companies operating in Iraq. Moreover, GoI demands private banks to raise their capital from 50 billion dinars to 250 billion dinars in order to expand the work and increase the activity of financing. This will increase the role of the private banks in supporting PPP contracts. On the markets, GoI needs to and works on improving the mechanisms of land acquisition.

Finally regarding the legal system issues, GoI is gradually creating the required institutional, legislative and methodical support. As the current investment law No. 13 is not suitable GoI needs to pass the new PPP law which promises successful implementation of a more solid background for future PPP contracts in Iraq.

In general, the demand for the infrastructure services and the availability of future projects for the private sector as well as the GoI actions are encouraging PPP approaches in Iraq. Overall it can be concluded that despite the current hindrances there are fair chances for successful PPP contracts in near future.

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PROCESSES IN CONSTRUCTION MANAGEMENT AND REAL ESTATE DEVELOPMENT – A SYSTEMATICAL APPROACH TO THE ORGANIZATION OF COMPLEX PROJECTS

Josef Zimmermann
Technische Universität München, Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung, Germany, lbi@bv.tum.de

Wolfgang Eber
Technische Universität München, Lehrstuhl für Bauprozessmanagement und Immobilienentwicklung, Germany, lbi@bv.tum.de

Abstract

As projects become large nowadays and still are unique and nonrecurring by definition they are subject to very sophisticated methods of control and management. In contrast to any stationary industries only well-organized predictive planning and scheduling as well as continuous and strong controlling activity can substantiate a fairly safe outcome and thus allow for successful projects on a very tight market.

Such is in particular valid for markets in Real Estate Management and in Construction Management, where volumes are large, durations long and safety margins low.

As experience cannot easily be taken from previous projects and projected directly on new tasks a high level of abstraction using models of proceeding is required. The use of abstract processes instead of product oriented activities allows for fairly well established degree of planning, scheduling and organization, quality assurance, training of staff and control.

In this paper we propose a rather complete set of structured control processes mapped on the basis of UML (Unified Modeling Language). Such an approach allows the introduction of some useful parameters describing the control effort to be taken into account in order to keep the project monetarily as well as technically on the scheduled course within the given margins. These parameters are e.g. the extension of well-known pure structural values like maximum ranks, grade of parallelism and complexity to adequate parameters describing the behavior of controlled activities on the time-axis.

We expect from the use of such a parameterization a fairly improved view on the certainty of completion and the respectively required control expense for complex projects, in particular in construction and real estate management.

Keywords: factors of success, strategic planning, project management, UML-modeling, processes.

1. INTRODUCTION

Projects are defined to be non-recurrent and unique and therefore resist attempts to be subjected to standard organizational structures [Schelle 2005, Wiest 1977]. This may be the reason why oftentimes prognostic estimations of duration and costs are very inaccurate, in particular in Construction Management and in Real Estate development, where volumes are high, markets are tight and margins of profit negligible. Nevertheless being major key parameters for an investor's decision to go or to leave there is much headroom to improve [Zimmermann 2008, 2009].

Usually the production itself is not imposing any problem besides technical challenges which are not targeted her. Yet the common use of resources physically or in an abstract meaning turns out to be of crucial relevance for successfully conducting a project. This is for example the fact that the project itself i.e. the goal is common implying that only if each and every element of the whole is finished appropriately, the objective is achieved [Malik 2003, Vester 1995]. Furthermore time and budget are common, as consumed shares of these are no more available for other elements keeping the total constant. In like manner the design plan is common since every element needs to fit in its place, the space to work in because if occupied by one trade no other has access etc. [Zimmermann/Eber 2010/2011].

Therefore optimized assignment of shared resources to the singular elements turns out to be a very challenging task requiring skills and significant effort to be spent on. This is defined as planning of organization in contrast to planning the design where all the technical and aesthetical decisions are made. Omitting the organization would save cost but the technical part will not be brought to operation [Zimmermann 2012].

As the product itself in particular in construction is completely defined by the respective procurement, potential vendors are forced to stick to the substance but need to mark themselves off from others by merely the organization part in quality i.e. reliability and efficiency and costs. Thus organization cannot be taken as a necessarily induced add-on to the construction but as the main service a provider is ready to deliver. Thus construction is basically not the delivery of a product but of a service where its grade is the relevant and distinguishing indicator on the respective markets which cannot be covered by simple percental surcharges. So far measures of precisely quantifying the expenditure and effort needed for such service are an urgent need.

In this paper a genuine structure is proposed intended to develop and establish organizational entities capable to lead the technical activities to a successful result within time, budget and to the desired quality. It is basically formed by a set of fundamental controlling elements, which can be valued according to its type regarding consumption of resources and therefore costs. Finally cumulating the different elements of control weighted with the respective levels of abstraction, counted in number and positioned to an explicit control structure is expected to deliver a well-founded and reliable calculation of applicable service charges. This approach follows the general idea of e.g. UML modeling making use of only a few well defined structural elements of which most complex systems can be formed, analyzed and evaluated [e.g. Funk 2010, ISO/IEC 19501 2005, Scheer 1997].

2. ELEMENTS FOR MODELING PROJECT EXECUTION

2.1. Work Break Down Structures

Creating a complex physical product is traditionally approached by disassembling the product into smaller sub-elements over several levels of disintegration until the finest resulting elements can be fabricated easily. This not only is meant to simplify the task but also allows for division of work making use of specialized crews to handle small elements more efficiently. Yet division of labor also includes the two major challenges of economics which is make people work together in terms of coordination and motivation. According to Picot et al. [e.g. Picot et al 2008] coordination considers the provision of knowledge for involved parties, i.e. the required information whereas motivation focusses on the in no way less important incentives to make people want to cooperate.

In this paper motivational aspects are put aside as they are assumed preconditioned by appropriate contracts. Yet the overall coordination according to Picot [2008] will be the subject. The decomposition of the product is directly followed by the decomposition of work, which produces the sub-elements [Vester 1995, Malik 2003]. Based on this classical Work-Break-Down structures (WBS) are used to map the complete project on a tree diagram from the theory of graphs where exactly one unique path leads from every node to the top [Schelle 2005, Kerzner 2003]. Formulated in terms of a package diagram UML [Booch et al, 2007] the project itself sits at the top broken up to sub-elements on several levels down to the most detailed level of working packages. Due to the nature of tree diagrams there is only one structural aspect to followed, be it the physical structure, some economic criterion or a functional analysis. For this reason several most important issues are necessarily neglected when denoted on a tree diagram [see e.g. Schulte-Zurhausen 2002]:

First of all the work packages have only vertical interfaces, where they are defined from. All interaction takes place in horizontal direction which would violate the tree structure. To solve this, in general the tree is expanded by the network structure connecting the activities which form the work packages regarding their causal time dependency only horizontally and are subject to well-known algorithms of scheduling (corresponding to UML activity diagrams) [Kerzner, 2003, Lewis 2002, Runzheimer 1978, Wiest 1977].

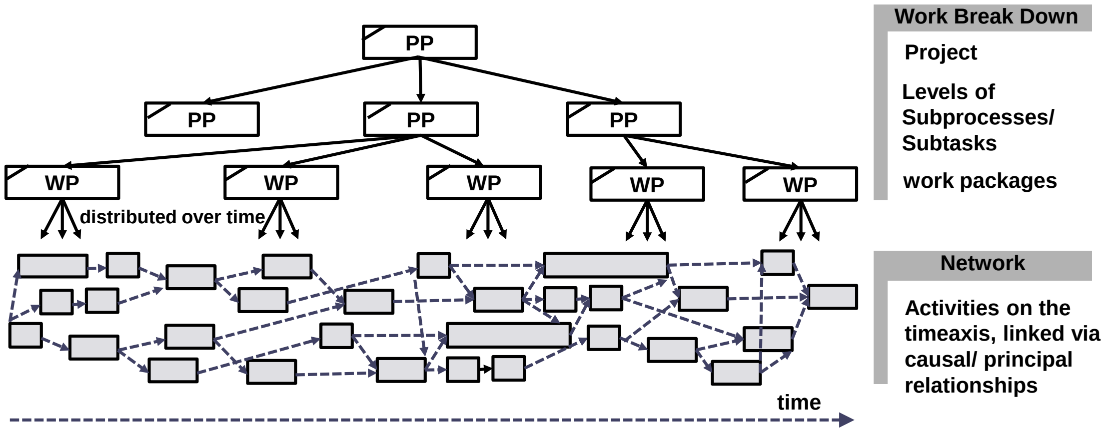

Figure 1: Work Break Down structure (UML-Package) and Network Diagram (UML-Activity)

Secondly with the separation of work packages all means to get hold of the complete project are lost. Therefore additional comprehensive tasks need to be introduced which fit in no way to the mentioned decomposing the original product as are e.g. project management, quality assurance, systems engineering, controlling etc. Since these need to be accomplished as well, they are somehow attached to the Work Break Down structure, yet not really integrated.

This paper proposes a generally valid structure for mapping complex projects to processes including the need of instruments that originate themselves from the odds and ends of the decomposing operation.

2.2. Production Processes

First of all we refer only to operations that need be done to achieve a goal, called processes, and avoid the need of talking about the specific product. These may reside on any level of complexity, could possibly comprise any number of sub-processes, need to be well defined regarding goal and resources and in particular are headed by one and only one responsible.

Just breaking up the process of producing the product itself into smaller elements as is done in a WBS establish the so called production processes (PP), each producing some physical or intellectual or informational result. They can be consistently structured as a tree, yet superior production processes are not designed to produce something themselves but to contain lower ordered production processes which at the least level would bear the name of work packages. These finally comprise activities which are responsible to do the actual work. Therefore the tree structure only helps to order subparts and define responsibilities and technical interfaces to higher levels.

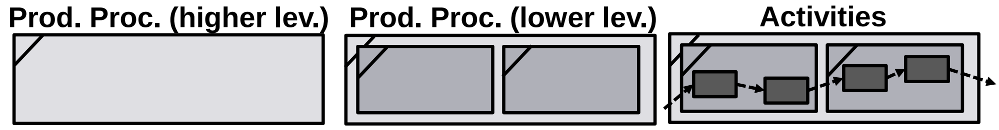

Figure 2: Hierarchical structure of Production Processes (UML-Package Diagram)

2.3. Control Processes

The multitude of production processes if properly designed would be capable to accomplish the desired result, yet with no securing the quality, duration and consumption of resources, i.e. not at all. Therefore additional processes of a completely different type are required to reside behind the world of production processes in order to establish and control them. These represent the actual service provided by the executing company and allow distinguishing themselves from other competitors on the market. Oftentimes treated as unwanted add-on on the actual production they now become more and more the central element of management and need to be calculated in detail. Therefore a fairly strict structure similar to the production is required in order to make their expenditure available for accurate calculation. They are called control processes and are defined as a set of eight fundamental types.

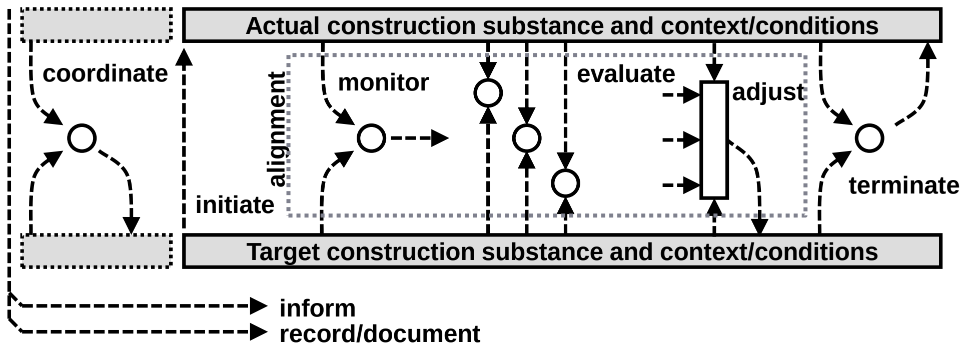

Figure 3: Fundamental Control Processes (UML-Communication Diagram)

Basically they are designated to operate the interface between the desired target configuration comprising the *target* construction substance and the *target* construction context and the *actual* situation comprising the *actual* construction substance and the *actual* construction context.

Coordinate (to be distinguished from the Picot definition), located ahead of each production process, evaluates the actual and the target situation and elaborates all required information for the production to be carried out. This is in particular a check for consistency and the very challenging task to identify missing information and to retrieve it.

Initiate makes the respective production process run as otherwise uncoordinated starts or purely accidental starts or no starts at all would be likely to occur.

During the run of the process it needs to be controlled in order to be sure about the proper achievement of the desired result. Therefore three control processes are subsumed with '*alignment*':

Monitoring the process operates on the target as well as on the actual situation and compares by means of approved measurement, counting and testing procedures. The result of these tests is immediately passed to the ***evaluation*** process which develops different scenarios of adjustment of the target context, e.g. assignment of resources and their possible consequences for the outcome of the process. Finally the ***adjustment*** process initiates the modification of settings and therewith reorientates the production process. Such an alignment cycle needs to be implemented on a regular basis in order to ensure controllability within a given scope.

At the scheduled end of the production process, the result needs to be checked again, which is identical to the monitoring process, needs to be decided for the scenario of accepting the result and then instead of applying adjustments the affirmatively successful ***termination*** of the process follows.

Two additional control processes work somewhat different from the previous as they are triggered continuously as something happens which needs to be passed as ***information*** and being under the need of persistency are ***documented***.

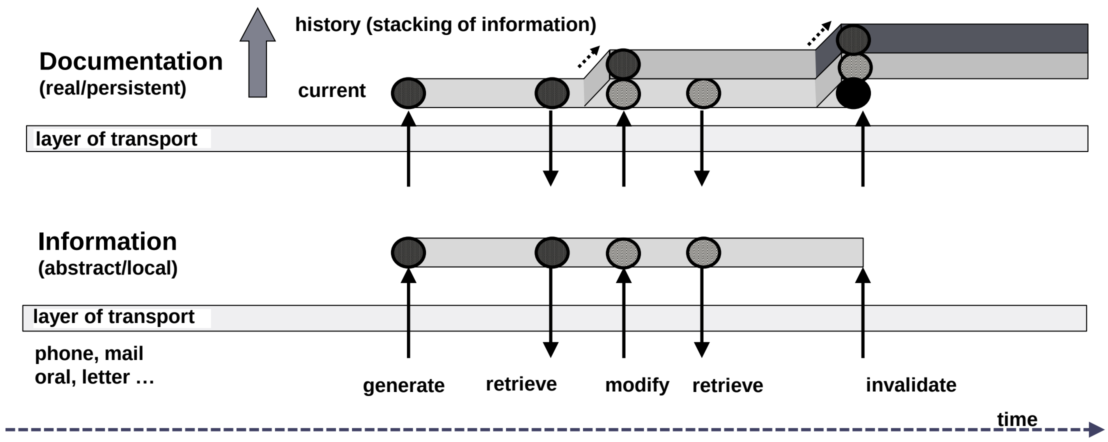

Figure 4: Information and Documentation

As control is the abstraction of making things work also information needs to be formalized. Therefore every elaboration or decision at the domain of the target as well as every measurement and reaction at the domain of the actual development generates information which needs to be passed to the appropriate parties. Thus information is generated on the time axis and can be retrieved whenever required. It can be modified as well and maintains validity until actively invalidated. Since every step in the execution of a project needs to be retraceable all the intermediate steps need to be recorded along with their history, called documentation.

Moreover information is generated in the first six control processes but not worked up there. The need of elaborating details from given information or *vice versa* condensation of information into overall parameters and key indicators is satisfied also within the process of informing.

2.4. Interaction between Production and Control Processes

Every production process requires a minimum set of control processes. The interaction of a production process with the details of the respective set of control processes on the time axis is plotted in Fig. 5.

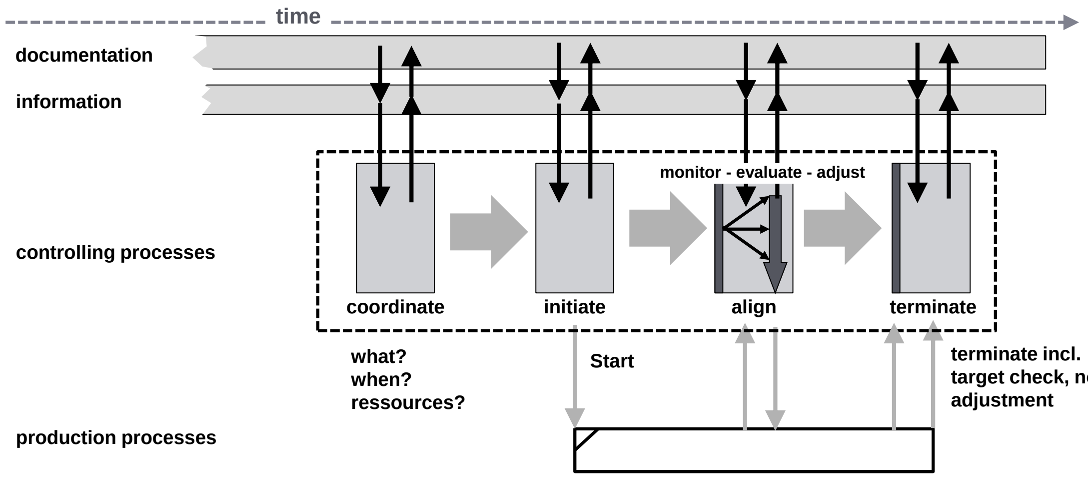

Figure 5: Minimum set of control processes handling a production process

A slightly different view on the same is given in Fig. 6 where the time axis is omitted and the perspective of the goal to be achieved becomes dominant. In this case the classical control loop is recognized starting with the setting of the goal, followed by the required coordination activities before initiating the production process. Then while running the alignment sequence (monitor situation, evaluate scenarios and adjust settings) is performed and leads again and again to initiating corrections until the result matches the target and the process can be terminated fulfilling the originally defined goal.

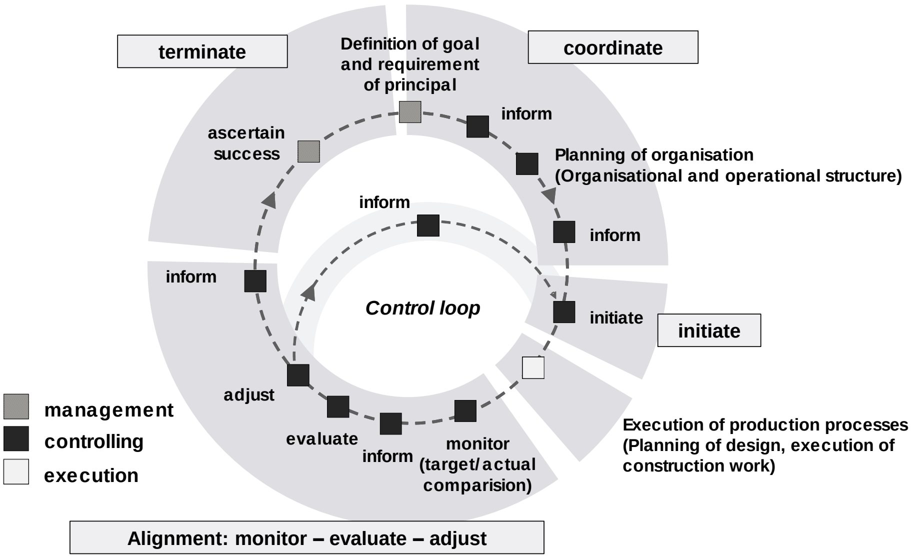

Figure 6: Control loop

Combined with the inherent time dependency the development runs like Fig. 7. The time distance between the execution of control loops and the scheduled or actual progress of work in between determines in accordance to the power of possible adjustment the so called controllability of the setting [see Zimmermann/Eber 2012] quantitatively.

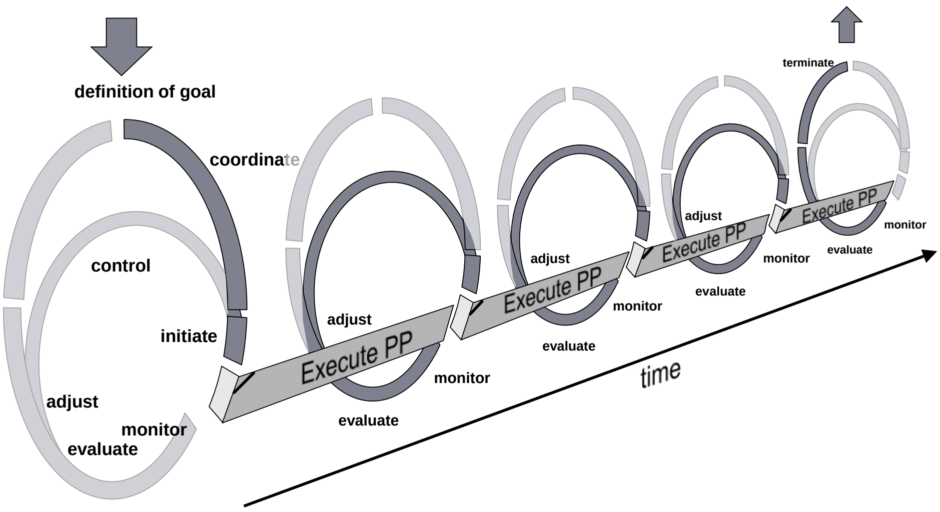

Figure 7: Control loop achieving a defined target over time

3. STRUCTURE IN MODELING PROJECT EXECUTION

3.1. Hierarchical Structure of Processes

Obviously a WBS displays division of work regarding production processes in horizontal direction while control needs to happen because of this. Yet also control needs to be accomplished and comprises processes which require resources themselves. Even the control tasks cannot be carried out by single persons or companies. As several individuals are sharing the control work there is division of labor to be taken into account as well. Avoiding the need to introduce another controlling instance to respond to this situation control processes are required to control themselves hierarchically i.e. in vertical direction. This leads to the structure described here:

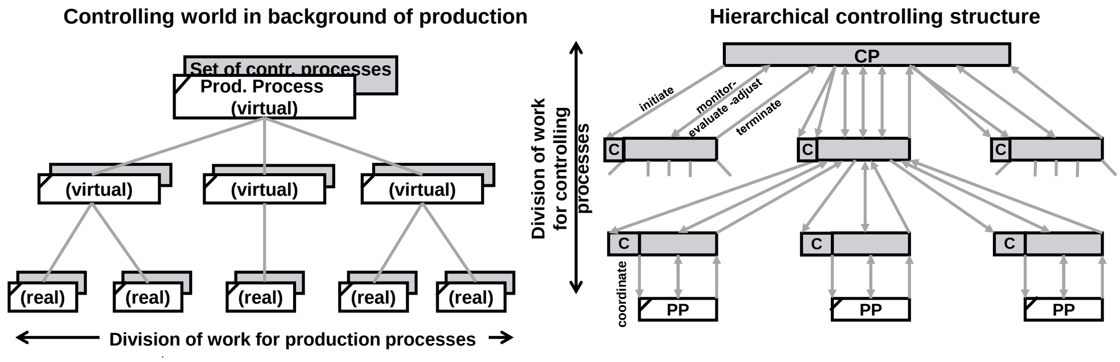

Figure 8: Hierarchically structured production and respective control processes

As for this some rules are valid in order to maintain a clear structure (Fig. 9 and 10):

- Each production process has its own set of control processes assigned.
- Superordinate production processes always contain the respective subordinate production processes.
- A set of control processes contains not but controls subordinate sets of control processes.
- Any operational access to a sublevel is always caused by the control processes Alignment (i.e. monitor – evaluate – adjust) and consequently leads to start Coordinate, Initiate, Monitor, Evaluate, Adjust or Terminate of the respective sub-process. Yet Alignment (i.e. monitor – evaluate – adjust) on any sub level may run on the levels own authority.
- Only the bottom line level of control processes operates on the real existing bottom-line of production processes i.e. on the work packages.

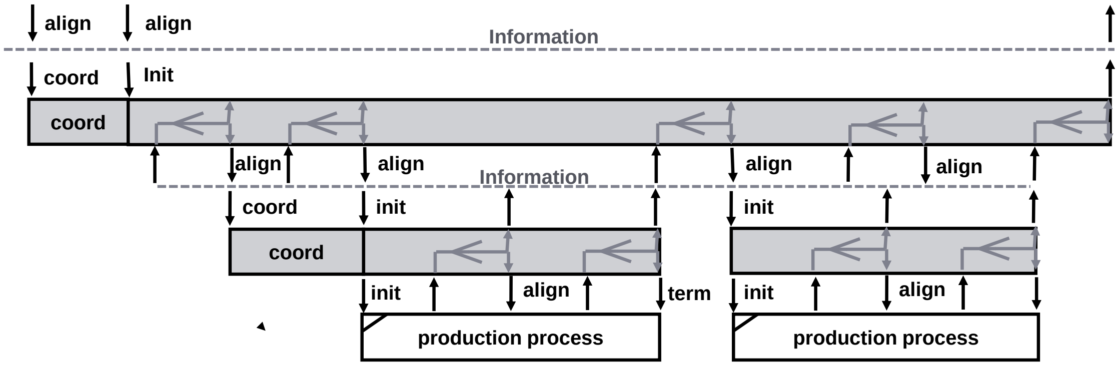

Figure 9: Interaction of control processes between hierarchical levels

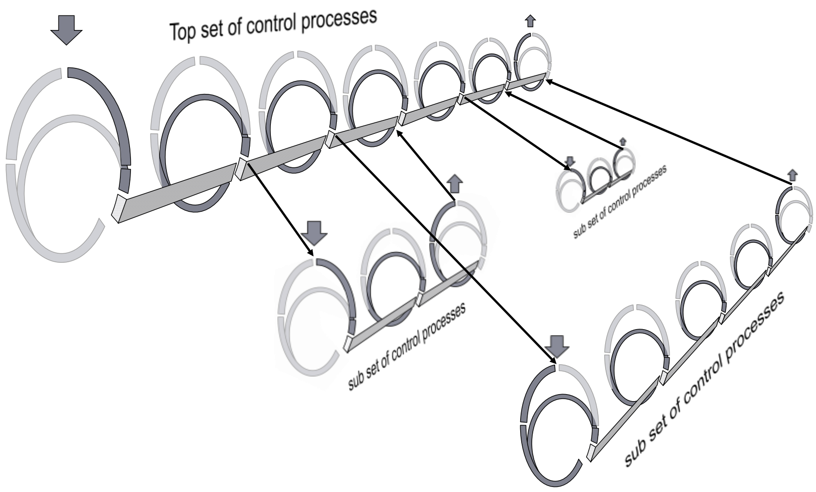

Figure 10: Goal oriented control loops over time

3.2. Interaction between Levels on Control Processes

Obviously control structures are required to make production processes run. They need to be performed on different levels of abstraction, knowledge and scope and thus by differently qualified and specialized personnel. E.g. a top level may operate issues of politics and law expressed in terms of contracts which defines level specific methods of monitoring and adjustment. On the other hand lower levels employing the same type of processes work on methods of leadership like incentives and motivation. Finally at the lowest level again identical processes are maintained administering physical measurement and activities of modification in order to keep the course of production within the scheduled corridor of quality. Therefore the different levels also signal division of work regarding control efforts, which need to be taken into account when assigning a weight finally leading to costs of the respective control processes. Included in the controlling activities are specific tasks processing i.e. translating information upwards and downwards as details need to be worked out from more complex decisions and go to lower sections while vast lots of information from bottom ends are to be condensed to key factors where decisions can rest on.

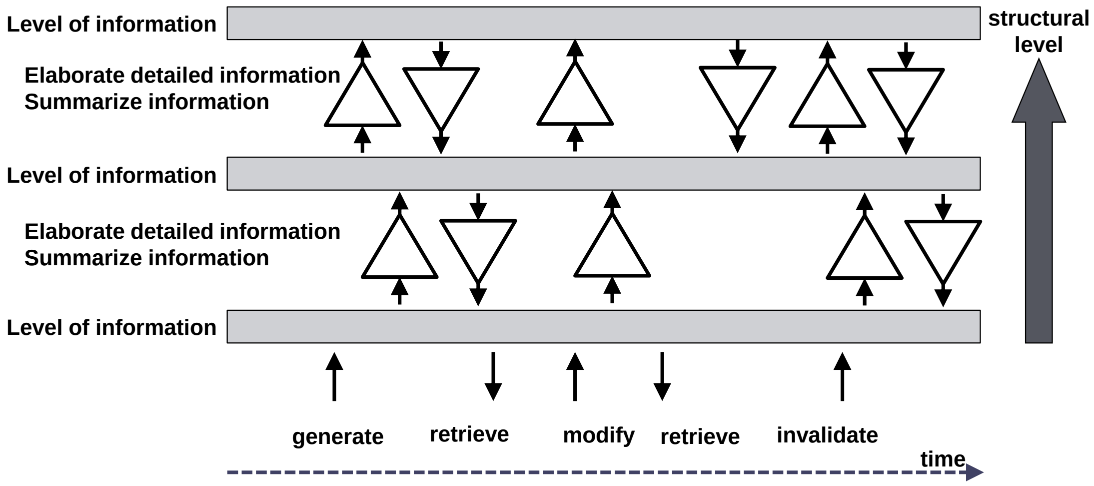

Figure 11: Information Management between Levels

4. CONCLUSIONS

Construction companies are forced to offer the production of exactly the required building or piece of infrastructure. As this is well defined there is no economic maneuvering room within the production processes. Yet the attached control processes are offered as service and may vary with the offerer in price as well as in efficiency. Thus the implementation of such with respect and optimized for the specific project is crucial as a distinguishing element on the tight markets in particular in construction management and in real estate development.

A set up as proposed here allows having this effort structured along the different levels of skills and tailored to the production processes. Most efficient organization structures are likely to evolve which will ensure the physical product to be created in time and budget as well as to the customer's required quality. Furthermore the effort needed for particularly this can be estimated in advance fairly well which is expected to lead to very reliable offers of the service. Since the structure of the organization is known only standardized control processes need to be evaluated and summed up according to their weight given by the type of process itself and the level the process is resting on. With this well-known structural key parameters like maximum ranks, grade of parallelism and complexity taken from the Theory of Graphs become available and sensible for judging and evaluating the required organizational effort for specific projects. Thus the actual costs of the offered services will become accessible in advance, even for singular and nonrecurring complex projects.

Additionally further research will reveal sensible types of project delivery systems as all the required control processes are to be distributed on all involved parties in a pattern where interfaces are minimized.

The fundamental and scalable mapping of structure of control is expected to dramatically enhance the secured treatment of unique and non-recurrent project tasks on a market dominated by price wars.

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DYNAMIC HAMILTONIAN BUILDINGS WITH A PERSIAN TWIST

Elaheh Zohrevandi
University of Tehran, Tehran, Iran, elahehzohrevandi@me.com

Effat Allahyari
Azad University of Kerman, Tehran, Iran, efi_kian@yahoo.com

Abstract

This paper is going to introduce an idea of building constructions based on Bio-architecture and Iranian Architecture. Architecture has a multidisciplinary nature and integrating it with Biology and Art can turn it into a versatile and a brand-new tool.

Human cells contain DNA. If the DNA double helix didn't fold, the genome in each cell would be two meters long. The genome has an unusual organization known in mathematics as a "Fractal Globule". It enables the cell to pack DNA incredibly tightly while avoiding the knots and tangles. Moreover, the DNA can easily unfold and refold during gene activation, gene repression, and cell replication (Different phases of a cell).

"Fractal Globule" can be modeled through a Hamiltonian Path, a lattice walk in which every point is only visited once and no paths intersect, this prevents knot formation. In this paper, "Knots" represent "Conflicts among priorities" and in order to avoid complexity, Hamiltonian Path has been used to model the buildings.

Buildings that are designed based on Hamiltonian Path can be moved without facing overlapped compartments. They can be unfolded to absorb light during the day and refolded to save energy at night. These buildings can be altered based on the inhabitants needs. Architecture is the art of satisfying the humans' needs. Based on the residents needs, a Hamiltonian Path with a specific number of knots can be designed.

Iranian Architecture is both structurally and aesthetically various. It can be a reminiscence of an ancient yet very glorious architecture style and adds a new touch to the Hamiltonian buildings.

Keywords: bio architecture, dna, dynamic buildings, hamiltonian path, persian architecture.

1. INTRODUCTION

Nature is the best designer in the world. For millions of years, designs have been evolved in nature. Biological designs that far exceed any human designs in terms of complexity, simplicity, performance, and efficiency are rich throughout the living world. From the shape of a shark, to the molecular structure of bacteria, every single living thing is a reflection of the power of natural design.

Nature is the best example of self-organized patterns. Natural patterns follow certain self-organization rules in which there is no such a thing as a main controller. Every particle is equal to the others. The whole structure keeps itself together by transferring information from one cell to the other.

Storing the greatest amount of information among the living organisms can be the best pattern to model in order to design a structure with many inhabitants having different needs. Genetic material is stored in chromosomes. Every human chromosome is nearly 2 meters long but the DNA is folded in a very special and unique way that can be only described by Hamiltonian Path. A Hamiltonian path shows how each of our cells stows some three billion base pairs of DNA while maintaining access to functionally crucial segments. In this paper, each crucial segment in DNA represents a part of the building with a higher priority regarding the inhabitant’s needs.

2. SECTION 2

2.1. Hamiltonian Paths: Building

In graph theory, a Hamiltonian path is a path in an undirected graph that visits each vertex (knot) exactly once. A Hamiltonian cycle is a Hamiltonian path that is a cycle. Adleman's successful solution of a seven-vertex instance of the NP-complete Hamiltonian directed path problem by a DNA algorithm initiated the field of bio molecular computing.

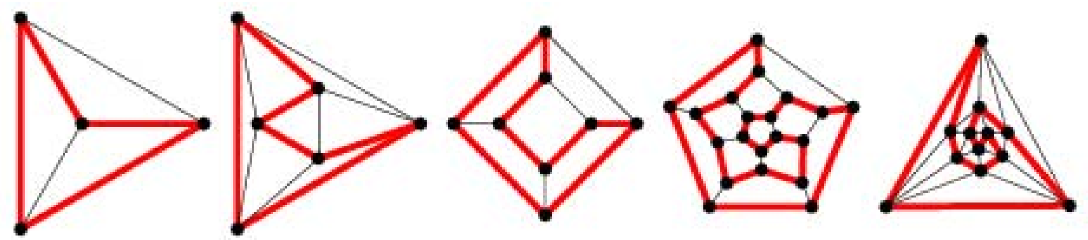

Figure 1: Hamiltonian Paths with different knots

One of the features of Hamiltonian circuits is that they can be unfolded, re-shaped and refolded without tangling. This feature can be used to build structures and buildings that need to be folded.

2.2. DNA: Movement

Nature has chosen a very clever solution to storing information -- a super-dense, knot-free structure called "fractal globule" which can easily be modeled and used to design a building that could fold in and out without facing tangles that might interfere with the building inhabitant's priorities.

The human genome is organized into two separate compartments, keeping active genes separate and accessible while sequestering unused DNA in a denser storage compartment. Chromosomes snake in and out of the two compartments repeatedly as DNA alternates between active, gene-rich and inactive, gene-poor stretches.

Gene-rich stretches represent the parts of the building where satisfy the needs of the inhabitant while the gene-poor stretches indicate the parts of the building satisfying needs with less priorities. The building can move in an out to absorb energy from the sun in the daylight and also ventilate just the way the genetic material snakes in and out of the two compartments.

Figure 2: DNA and a Hamiltonian Structure

Folding is relatively old yet very modern technique in Architecture. Origami has been recognized by many mathematicians, biologist and engineers and many implementations have been achieved so far. In architectural and industrial design, where the final form can be more important, origami plays a crucial role.

Another important field of application of origami can be considered under the discipline of "Bio-mimesis". The foldable nature of origami provides a very powerful medium in understanding several deployment modes in nature and thus the structural relations among different components.

In the following section, DNA origami will be introduced as the material of the walls in Dynamic Hamiltonian Buildings.

2.3. DNA Origami: Walls

DNA self-assembly is an emerging technique in DNA nanotechnology. Recent advancements in technologies and ideas have spurred new growth in the area. To keep the temperature of the building and provide a recyclable and cheap energy source, we can make the walls of the whole building using DNA Origami. DNA origami is the Nano-scale folding of DNA to create two-dimensional and three-dimensional shapes at the Nano-scale. If the tubes in the walls of a Hamiltonian Building are connected using DNA Origami methods, the heating and the energy circulation of the whole structure would not damage if the building moves in an out to absorb energy from the sun in the daylight.

Figure 3: DNA Origami tubes make up the walls of a flask turning it into a knot-free structure

Long strings of DNA have crossovers and these crossovers give the DNAs the ability to bend without breaking. With designed crossover points at desired positions, DNA helices can be linked together so that different sized curvatures in and out of the plane can be achieved.' The remarkable combination of "Crossovers at the right places" and "the angles with the right degrees" gives us the whole image of a Hamiltonian building.

2.4. Persian Architecture

Iranian architecture has these main characteristics: Introversion, Structure, Minimalism and homogeneous proportions.

Although Iranian Architecture is various in styles, certain design elements of Persian Architecture have persisted throughout the history of Iran. The shapes used in Persian architecture are simple, profound, and full of meaning and represent figures of perfection, freedom, prosperity, power, firmness and totality. Spaces made by these shapes are solid and relaxing with a sense of peace and confidence. They also reflect the feeling that the building has always been like this and will always be. This style of architecture (Persian architecture) has been chosen for the Dynamic Hamiltonian Buildings to maintain a balance in a place where the sense of having a dynamic and unstable place that moves in and out exists.

Persian architects make the space like a faceted precious stone, as the internal design of the place is also very important to them. The design of the ceiling is very important to them although the internal design does not end with the ceiling. The vaulted decorated ceilings, Muqarnas, are different in shapes and sizes and they are very mysterious. Muqarnas can give a sophisticated yet very glamorous twist to the Dynamic Hamiltonian Buildings.

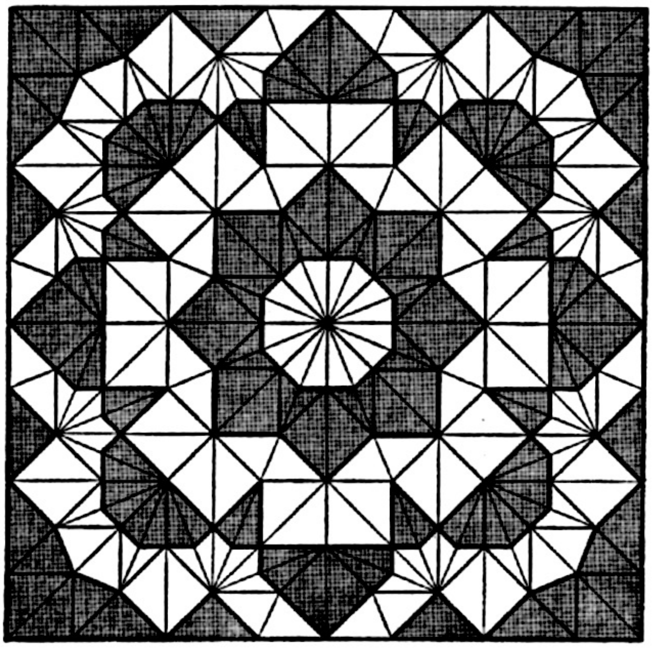

Figure 4: Muqarnas (Ceiling)

The outer design of the building that has been visualized by Effat Allahyari can be seen in figure 5 and figure 6.

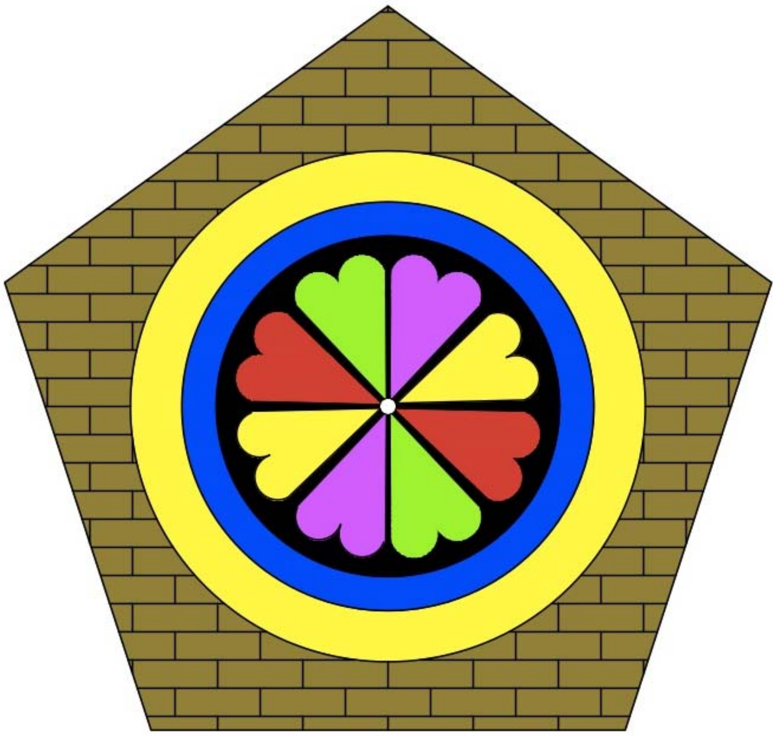

Figure 5: The exterior design of a Dynamic Hamiltonian Building wall

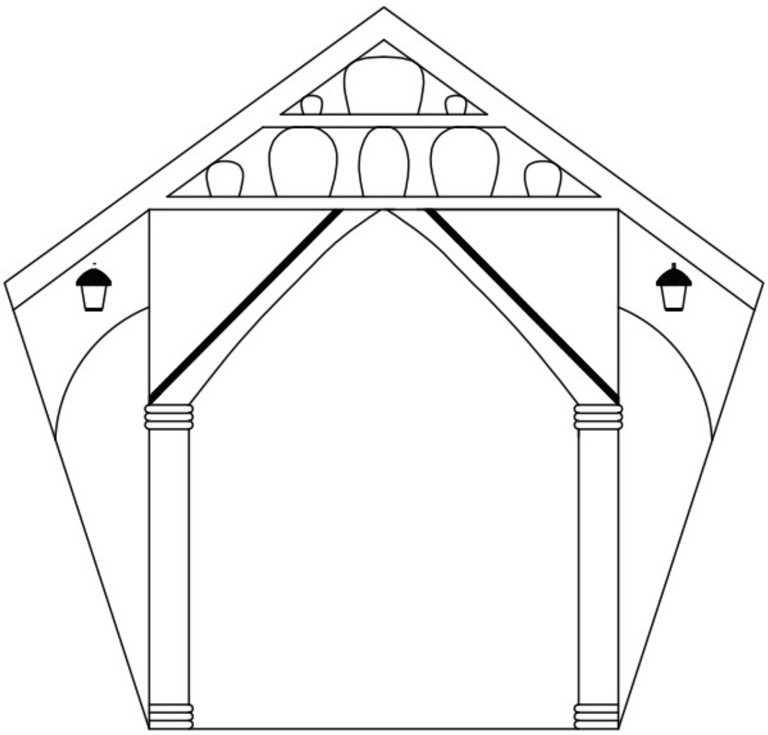

Figure 6: The entrance of a Dynamic Hamiltonian Building

3. CONCLUSIONS

In this paper, a new style of architecture is presented which is a combination of Bio-architecture, Bio-mimesis and Persian Architecture.

Dynamic Hamiltonian Buildings are designed using bio-architecture methods combined with Persian architecture. The main features of these buildings are their dynamic nature which enables the buildings to move, the Hamiltonian nature which enables them to move in and out of their structure without facing knots or getting tied in and the Persian style of the exterior and interior design which gives a mysterious look and feeling to the structures.

DNA Origami is also discussed in this paper. Mimicking the DNA Structure and how it folds automatically can make up a highly effective pattern for designing the walls of these buildings.

Acknowledgement

The idea wouldn't have turned into a real deal without the help of Elmira Zohrevandi.

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