Proceedings of the

10th International Conference on Construction in the 21st Century

Colombo, Sri Lanka

July 2-4, 2018

CITC-10

10th Anniversary

Editors:

Syed M. Ahmed, Attaullah Shah, Salman Azhar, Norma A. Smith, Shaunna Campbell, Kelly Mahaffy, and Amelia Saul

Abstract for the Proceedings of the

Construction in the 21st Century 10th International Conference

July 2nd-4th, 2018 – Colombo, Sri Lanka

Editors

Syed M. Ahmed
East Carolina University, Greenville, North Carolina, USA

Attaullah Shah

City University of Science and Information Technology

Salman Azhar
Auburn University, Auburn, Alabama, USA

Norma A. Smith
East Carolina University, Greenville, North Carolina, USA

Shaunna C. Campbell
East Carolina University, Greenville, North Carolina, USA

Kelly Mahaffy
East Carolina University, Greenville, North Carolina, USA

Amelia Saul
East Carolina University, Greenville, North Carolina, USA

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Foreword

While technology and innovation are shrinking the distance between countries and industries, leadership and collaboration are actively shaping the construction industry and guiding it to success. Construction in the 21st Century (CITC) is an organization backed by East Carolina University in collaboration with Auburn University, Florida International University, City University of Science and Technology, Ceylon Institute of Builders, University of Moratuwa, University of Wolverhampton, Western Carolina University, and Babcock University. CITC executes international conferences to bring together like-minded construction management professionals. The CITC-10 conference seeks to bring together an international group of practitioners, researchers, and educators to promote a novel exchange of ideas in a multidisciplinary fashion.

CITC-10 is a peer-reviewed conference that acts as a dynamic conduit for the exchange of knowledge. New methods and techniques must be carefully scrutinized and rigorously tested before implementation, and CITC-10 plays an integral role in this process. As the industry moves forward in an ever-complex global economy, multi-national collaboration is crucial. Future growth in the industry will undoubtedly hinge on international teamwork and alliance.

This July marks the tenth CITC conference. Previous conferences include CITC-I in Miami of 2002, CITC-II in Hong Kong of 2003, CITC-III in Athens of 2005, CITC-IV in Gold Coast, Australia of 2007, CITC-V in Istanbul of 2009, CITC-VI in Kuala Lumpur of 2011, CITC-VII in Bangkok of 2013, CITC-8 in Thessaloniki, Greece of 2015, and CITC-9 in Dubai of 2017. All conferences were tremendously successful. As with previous conferences, this effort has been greatly supported by our friends and colleagues across the globe. It is our pleasure to now present to you the Tenth International Conference on Construction in the 21st Century (CITC-10, Sri Lanka). This two-and-a-half-day conference is being held in Sri Lanka at Hilton Colombo. CITC-10 will bring together a diverse group of academics, professionals, government agencies, and students from all over the world to contribute to the future growth of the industry.

We intend to hold the CITC series of conferences at regular intervals. We gratefully appreciate your attendance, and hope that you will support the future endeavors of CITC.

Thank you and kind regards,

The Editors

Syed M. Ahmed, Chair

Attaullah Shah

Norma A. Smith

Shaunna Campbell

Salman Azhar

Kelly Mahaffy

Amelia Saul

ISBN: 978-1-7324416-1-3
July 2018
Greenville, North Carolina, USA

CITC-10 Themes

- Leadership in Engineering & Construction
- Architectural Management
- Building Information Modeling
- Automation and Robotics
- Lean Construction Practices
- 3D Printing
- Augmented and/or mixed reality
- Legal issues in Construction
- Value engineering
- Procurement Management
- Project and Program Management
- Quality and Productivity Improvement
- Risk Analysis & Management
- Sustainable Design and Construction
- Concrete Technology
- Construction Contracts
- Construction Equipment Management
- Construction Safety
- Construction Scheduling
- Cost Analysis & Control
- Cultural Issues in Construction
- Design-Build Construction
- Engineering & Construction Materials
- Ethical Issues in Engineering and Construction
- Information Technology and Systems
- Infrastructure Systems and Management
- International Construction Issues
- Innovative Materials (ultra-high-performance concrete, self-healing concrete, photocatalytic "self-cleaning concrete," etc.)
- Asphalt concrete (super-pave, etc.)
- Recycled and waste materials
- Fiber reinforced polymers
- Curing compounds
- Nano-materials in infrastructure projects
- Girder bridges with superior structural performance
- Road and bridge barrier design
- Arch bridges, suspension, and cable-stayed bridges
- Bridge construction systems
- Value engineering

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

The Potential of BIM Models as Legal Construction Documents for Sustainable Growth in the Kenyan Construction Industry.

Kimani Thomas Njuguna
(Department of Construction Management, JKUAT, Nairobi, Kenya)
kimani.thomas.n @gmail.com

Mugwima Njuguna
(Center for Urban Studies, JKUAT, Nairobi, Kenya)
mugwima@gmail.com

Ahmad Omar Alkizim
(Department of Construction Management, JKUAT, Nairobi, Kenya)
aalkizim@gmail.com

Haddy Jallow
(BIM Engineer, Carillion UK)
haddy.jallow@kier.co.uk

Abstract—Building Information Modeling (BIM) has transformed the global construction industry in terms of generation, sharing and integration of design data. This has created a requirement for new protocols, activities and definitions. In Britain, the BIM overlay to the Royal Institute of British Architects (RIBA) Outline Plan of Work provides straightforward guidance on the activities needed at each RIBA work stage to successfully design and manage construction projects in a BIM environment. In the United States, two different contract addenda (E202 Building Information Modeling Exhibit and Consensus Document 301 BIM addendum) allow the contracting parties to decide whether or not BIM is to become part of the contract. The Kenyan construction industry has been using the traditional two-dimensional environments to define construction contracts. This paper suggests that as it happened with the introduction of Computer Aided Design (CAD), a tipping point will soon be reached where BIM will gain widespread local acceptance as a transformative technology and working philosophy at all scales of practice. However, with the incremental changes in projects delivery, particular concerns regarding the legal and contractual implications of BIM arise. Firstly, whether BIM will alter the traditional allocation of responsibilities for all project stakeholders. Secondly, whether standard forms of building contracts should be altered to account for the use of BIM. To assess these concerns, a survey was conducted within Nairobi with a sample of 24 industry experts from firms that have used BIM in at least one project. The data collection methods were semi-structured face-to-face interviews. Analysis of the data was done using content analysis. The findings show that consultants are adopting the use of BIM technology for projects delivery. This paper concludes that there are strategic benefits of developing BIM expertise in Kenya and that a BIM addendum, to be attached

to standard forms of contracts needs to be prepared to facilitate working at various BIM maturity levels for a sustainable growth in the Kenyan construction industry.

***Keywords*—BIM, Contractual Arrangements, BIM Maturity Levels, Collaboration, BIM addendum.**

1. INTRODUCTION

THE Kenyan construction industry contributed 7.4 percent of GDP in the year 2016 (KNBS, 2016).

The sector is worth about 8 trillion Kenyan shillings (80 Billion USD) per annum.

There's unrelenting pressure on the industry to increase productivity, quality and value and there is broad consensus, spread across the industry and its stakeholders, that construction under-performs in terms of its capacity to deliver value and that there has been a lack of investment in construction efficiency and growth opportunities (Ofori, 2000) . Additionally, poor and inconsistent procurement practices, in both public and private sectors, lead to wastage of resources and inefficiency. This is compounded by high levels of corruption, low levels of standardization and fragmentation of the industry. These challenges arise because the construction process is usually complex and involves many processes and parties, information is usually exchanged through the use of sketches, texts, emails, images, documents and drawings which can result in miscommunication and could hinder productivity in a construction project.

Over the past three decades, technology has contributed immensely to the development of various nations. There's need to manage information properly and the utilization of Building Information Modeling (BIM) will aid in meeting this objective. BIM appears to be one of the most promising recent developments in digital engineering in the construction industry. According to Talebi et al. (2014), Studies have revealed the benefits and challenges of BIM adoption in construction projects. A global survey by McGraw Hill (2014), found that 75% of highly BIM engaged consultants and contractors perceive that BIM has the ability to capture most detailed comprehensive information of a building project while 41% of contractors perceive that the reduction of design errors using clash detection as the top ranking benefit of BIM adoption. 21-23% of consultants and contractors value efficiency in quantity take-off and cost estimating (reduced construction cost) while 19% of consultants and contractors value 4D models to support construction analysis, planning and visualization for the onsite project team reducing the overall project duration. This illustrates that there are productivity gains through BIM adoption on construction projects in Kenya.

Even though the driving forces for digital engineering and building information modeling for construction are revealing globally, national level standardization and policy initiatives vary significantly in different countries (Smith, 2014). Countries like the USA, the UK, Singapore and Finland are leading in BIM policy regulations and adoption, while in countries like Kenya, policy initiatives and adoption are still slow, there's also little documented evidence of construction players implementing BIM in their projects. This is because, especially in developing countries, the majority of construction industry players see BIM as a disruptive technology that causes problems in the traditional construction process by transforming it into a new process (Eastman, Teicholz, & Sacks, 2011). However, knowledge and innovation have played a crucial role in development throughout human history and therefore developing nations like Kenya should treat their future in technology with some urgency.

In Kenya, BIM is facing huge challenges from the construction industry players because they are reluctant to change the traditional process and this is closely related to human and organizational culture. According to Arayici et al. (2011), these challenges include managing resistance to change from the construction stakeholders, making them understand the BIM benefits compared to traditional 2D drafting, managing education and training in BIM and explaining new roles and responsibilities of different stakeholders in BIM. There are also technical challenges related to use of BIM in developing countries like Kenya. Abubakar et al.(2014), summarize them as upgrading technology, interoperability, compatibility and complexity.

This study conducts a comprehensive review on the BIM implementation strategies and status in Kenya coupled with international and national strategies, regulations and policy initiatives globally and makes conclusions and recommendations to facilitate working at various BIM maturity levels in the Kenyan construction industry for a more efficient working environment.

2. BIM - BUILDING INFORMATION MODELLING ADOPTION

BIM, WHAT IS IT?

From the foregoing and considering the practical implications of BIM on the current working processes, it is vital to consider its definition.

BIM is the acronym for 'Building Information Modeling' which is commonly defined using the Construction Project Information Committee (CPIC) definition as the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its life cycle, from earliest conception to demolition (RIBA, 2012). Therefore, BIM is an electronic process which manages the planning and designing of buildings.

The most logical way to understand BIM is to refer to the widely used BIM maturity diagram prepared by Mervyn Richards and Mark Brew in 2008, as illustrated in the figure below.

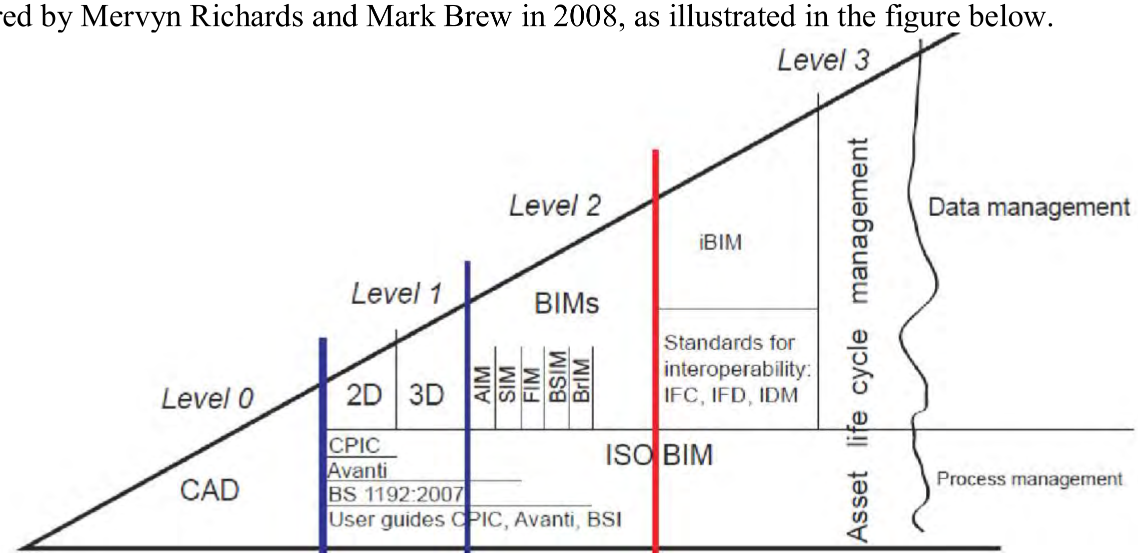

Fig 2. BIM Maturity Diagram (Source: Brew and Richards, 2008).

According to Richards and Brew (2008), the level of BIM adoption can be differentiated based on the maturity levels.

BIM level 0 is usually defined by 2D environments with unmanaged CAD coordination, most formats are papers and electronic e.g. .dwg and .pdf files. These formats are treated as the main data exchange mechanisms. Majority of design practices in Kenya are currently using this process. From the diagram, it's important to note that there's no process or data management at this stage.

BIM level 1 involves managed CAD in 2D or 3D format with a collaborative tool providing a common data environment possibly using some standard data structures and formats. In Kenya, 3D software is mainly used as a conceptual tool in architecture in the early project stages and for visualization of the finished project. Globally, level 1 embraces the need for management processes to move alongside design processes, this is captured in BS 1192:2007, collaborative production of architectural, engineering and construction information - code of practice.
Level 2 BIM involves working in a managed 3D environment held in separate discipline "BIM models" and tools with attached data. Data exchange is mainly on the basis of proprietary of exchange formats. This approach may include 4D program data and 5D cost data. All key members of the design team must produce 3D information models, the models need not co-exist in a single model but each designer's model must progress in a logical manner so that it can be used by another designer.
The outputs required at each stage require greater definition, and in turn require the project manager to clarify the inputs that they require at each stage of the design in order to co-ordinate the design as it progresses. Another requirement is the replacement of the currently fragmented design team from the contractors to be replaced by integrated teams working collaboratively under new forms of procurement using new working methods (Chan, 2014). This will be a challenge for Kenya as the consultants work during the pre-construction process before bringing the contractors on board.
Level 3 BIM is a fully open process with a single project model and data integration and exchange using Industry Foundation Class (IFC) standards; the process is managed by a collaborative model server. The challenge with working with one model is the harnessing of the information in the model so that it is of great use (Teo et al., 2015). For the information to have great value, software interoperability will be required.
However, with level 3 BIM, it will be possible for early rough and ready design analysis on environmental performance minimizing iterative design time, cost models to be derived quickly from the model using new costing interfaces, health and safety aspects associated with the construction and maintenance of the building to be analyzed parallel with the design and asset management, Key Performance Indicators (KPI) and other information to be aligned with intelligent briefing, enabling information in the model to develop during design and to be used as part of soft landings approach, and to inform and improve future projects (RIBA, 2012). This will be very helpful for the Kenyan construction industry where a lot of time is spent during design, projects usually have cost over-runs, health and safety aspects are not well coordinated and environmental factors are given minimal consideration.

3. METHODS

An inductive qualitative approach was used to provide for an enhanced understanding of BIM in the Kenyan construction industry. An interpretivist research philosophy was also adopted and since there was no prior hypothesis to be tested, an exploratory study was used to inform the research. Literature review was conducted to examine the definition, concepts, application and all related issues of BIM. Exploratory interviews were conducted to collect data from the perspectives of purposefully sampled construction industry players (The Government, Clients, Project Managers, Architects, Engineers, Quantity Surveyors and Contractors) in Nairobi, Kenya. 24 semi-structured face to face interviews were conducted over a 3 month period. An interview guide was used to collect data for the fulfillment of the research objectives. Materials from pervious desk studies were used to prepare for the interviews, all interviews were approximately 1 hour in length for each respondent. The respondents had experience in using BIM in at least one of the projects they were involved in. The data was then analyzed by the authors using the technique of context mapping.

4. FINDINGS AND DISCUSSION

The research questions of this study were whether BIM will alter the traditional allocation of responsibilities for all project stakeholders and whether standard forms of building contracts should be altered to account for the use of BIM in the Kenyan construction industry. This can be summarized as the legal implications of BIM in the Kenyan construction industry. However, to support this, other themes emerged during the interviews which are National and organizational culture, technology transfer and government recognition and support. All the factors are closely related and are major factors in ensuring the successful implementation of BIM in the Kenyan construction industry.

Organizational Culture, Technology Transfer and Government support

According to literature (Bin Zakaria et al., 2013; Bryde, Broquetas, & Volm, 2013; Masood, Kharal, & Nasir, 2014; Teo et al., 2015), there is evidence of the benefits that the Kenyan construction industry could gain by implementing BIM. However, Kenya has not realized this because BIM implementation is still low. The main reason for this is that there's little knowledge about BIM and the majority of the respondents believe that most of the consultants and contractors do not know why, how, when and what to start. This is because there is no standard of BIM implementation at the national level for them to follow. Some of the firms in Kenya are trying to be BIM champions by developing their own version of BIM implementation guidelines while some are influenced by expatriates especially when working on international construction projects and end up using the standards and guidelines of the foreign country. However, the outcome is confusion at the industry level.

According to one of the respondents, the main challenge in BIM implementation is that there are no national standards or guidelines; since BIM in Kenya is still at its nascent stage, there is need for the government to urgently set up a team or committee to develop the national BIM guideline. Additionally, one of the respondents, an engineer, still doubts the effectiveness of BIM because of the limited information that has proved the effectiveness of BIM in the Kenyan context. However, another respondent, an architect stated that he has used BIM in three of his projects and some of the major benefits were the reduction of design changes and discrepancies between contract documents especially the architectural, structural and services engineering drawings/ models by detecting clashes and design conflicts early enough. Another respondent, a quantity surveyor, uses BIM for quantity take off and costing stated that the Bills of Quantities that his firm produces using BIM are more accurate and the client is able to make proper funds arrangements expecting little or no cost variations in the building costs.

According to Masood et al.(2014), the lack of highly skilled staff and BIM knowledge causes the majority of industry players to fail in realizing the benefits of BIM. One respondent, an engineer, suggested that a series of awareness programs, which could be funded by the government, should be undertaken to promote the use of BIM in construction projects.

Additionally, organizations are facing challenges from within. Resistance to change, fear of the unknown and lack of knowledge are some of the challenges. To manage these issues, one respondent stated that in his firms case, they bought a BIM software and one of the key staff members was trained on BIM, then the staff member trained his co-workers and BIM knowledge was disseminated throughout the firm, they created a new role of BIM coordinator. This shows that companies and organizations can assess their individual challenges and develop a custom BIM roadmap which can be as simple as migrating from BIM level 0, to 1, to 2 within a specific time period and strategy. The approach is different for one of the respondents, from an international architectural firm based in Kenya, he stated that their company had to act fast due to their international presence and now use BIM to add value in their profile while bidding for projects. Currently the firm is working on BIM level 2 in selected projects. However, the architect suggested that working together with a BIM expert should be mandatory for first timers as it could speed up the BIM adoption process and minimize associated risks.
From the interviews, it is evident that the readiness for the Kenyan government and local firms to adopt BIM will be heavily influenced by top management support. This is because BIM will change established work processes to a new work process that will require bold decisions. Below is a brief SWOT analysis of BIM in the Kenyan Construction Industry context.

Strengths	**Weaknesses**
• Saves time and money (Reduces waste, the team gets it right at the first time). • Improves 3D design capacity. • Simulates construction sequences. • Reduces Risks and errors. • Reduces energy use over a building's lifecycle. • Can be used by SME's.	• There's no culture of collaboration across disciplines. • The focus is on the buildings not information. • The government needs to take the lead. • Design firms and contractors need to work together. • There's no universal design standards. • There are initial hardware, software and training costs.
Opportunities	**Threats**
• Linkage with international leaders in BIM education. • Integrating with simulated training innovations. • BIM is the DNA of future construction. • Development of new skills and knowledge for the local industry. • Kenya can be a leader in BIM education and use in Africa.	• BIM will change the traditional ways of working in the local construction industry. • New types of contracts/ contract addenda will be needed. • There's limited understanding of BIM. • There are few firms working together, across disciplines. • Resistance to change.

Figure 3: BIM adoption in Kenya - SWOT analysis (Source: Authors).

The Legal implications of BIM in the Kenyan Construction Industry

The significant legal implications associated with BIM can be summarized into five categories namely; Model ownership, Intellectual property rights, Third party rights, Roles and responsibilities, and duty of care. Interview questions were drafted with the intention of investigating the industry perceptions as to how these particular legal implications should be approached in Kenya.

For model ownership, the interview results were conflicting as some of the respondents argued that the use of BIM does not change the inherent principles and ownership should lie with the designer while others argued that there's the likelihood of several model authors and this would require a complicated joint ownership or maybe the client (once it's complete), project manager or lead designer should assume ownership (during production). However, model ownership was not considered very critical for the Kenyan construction industry.

Intellectual property rights are closely linked to model ownership. This is basically the ownership of information embedded in the elements of the model. This is especially critical since even though a party may have ownership of a model, they may not necessarily hold the intellectual property rights of certain design elements in the model. The respondents did not generally consider the issue of intellectual property rights as critical for the Kenyan construction industry. One of the participants states that "Every project is unique and different. It's ridiculous for consultants to keep trying to protect their intellectual property rights". Additionally, the respondents unanimously agreed that guarding intellectual property rights conflicts with the idea of open and collaborative communication that BIM creates.

Privity of contracts dictates third party rights, this is where a third party cannot enforce conditions of a contract between the primary parties to that contract. According to Ashcraft (2008), with multiple contributors to a BIM model, the legal obligations of the various parties involved with a project will become blurred. One of the respondents in the study was concerned that information contained in a model may end up being used by third parties for purposes that it was not originally intended for. However, this concern conflicts with the principle of BIM that a model should enable the unrestricted flow of information in order to extract maximum value for all parties. Most of the respondents were of the view that third parties should be able to rely on the model, as long as the users were authorized from the outset of the project. Defining the authorized users of a model will somehow address the issue of privity of contract as it would identify the intended benefit conferred to the third party and thus the English law of contract and the Law of contract act 2012 will still be applicable (Kenyan law of contract act CAP 23).

On the issue of duty of care, there were conflicting views as to what impact BIM will have on the duty of care of architects and engineers. However, according to Ashcraft (2008), BIM will cause an increase in the level of duty of care due to the enhanced clash-detection that BIM enables but increased clash - detection will give rise to an increased use of risk transfer methods such as indemnification agreements to decrease professional liability (Yarmohammadi & Ashuri, 2015).

On the issue of roles and responsibilities, all of the participants were of the view that there won't be a change in the job that every team member does in a project, BIM will only help them do it better.

The Implementation of BIM in Kenyan Standards Contracts

One of the anticipated challenges to implementing BIM in Kenya is the fact that most, if not all, of the standard forms of contracts completely ignore BIM and therefore, perhaps most importantly, how can they enhance rather than limit the benefits to be gained through the use of BIM.

Any discussion on BIM integration in each form of Kenyan Standards of Contracts is beyond the scope of this paper. This paper does not address specific legal issues that may arise from the use of BIM, it only suggests a contracting approach. The best contracting approach would be by the use of a new document dealing with BIM (a BIM Addendum).

The BIM addendum should incorporate the best practices in the use of BIM techniques and technology. The document should be fair and balanced for it to be acceptable to all parties involved in a project utilizing BIM. It should further address all the issues raised in this study. Therefore, rather than attempt to draft a BIM - specific standard form of agreement between the client and the consultants or between the owner and the main contractor, it would be more effective to attach a BIM addendum into the standard forms of agreements. The proposed attachment would modify the terms of the standard form of agreement to which it will be attached and will address all BIM - related issues that are beyond the scope of the standard form of agreement.

The main goal will be to create a document that will enable contracting parties to easily and effectively introduce virtual design and construction or building information modeling into the Kenyan construction industry while still retaining the standard form documents.

5. CONCLUSIONS

Global trends have indicated an increase in BIM implementation and this is set to continue accelerating into the future. Government initiatives in Singapore, United Kingdom, United States, Finland, Norway, Denmark among other countries are helping all construction industry stakeholders realize the benefits of this technology. Such developments should encourage BIM implementation on a wider scale as developing countries like Kenya might be left behind if they don't keep pace with the trendsetters in the BIM field.

The transition from the traditional approach to BIM in the Kenyan construction industry will not be an easy process. It will need decision making and change management strategies which will be guided by top management in the government and private sector. The government will be very instrumental during the transition period from previous traditional workflows to BIM workflows, convincing professionals about the potential of BIM, developing education and learning strategies and understanding new roles.

Firms and practices should also understand that when implementing BIM, there will be initial costs. To reduce the risks associated with BIM, the management at the firm level will have to phase BIM implementation gradually moving from BIM level 0, to BIM level 1, 2 and 3 eventually.

Since current BIM implementation in Kenya lies between BIM level 0 and BIM level 1, recognition and support from the government will improve the productivity of the construction industry and implementing BIM in public construction projects should lead the way.

The construction industry is following the globalization of the economy as international barriers are increasingly being removed. Therefore, competition for projects will not be local with companies with little or no BIM capabilities but will be international with companies with developed BIM capabilities and expertise at the bidding table. The strategic benefits of developing BIM expertise in Kenya will only be realized if the government and the private sector work together creating a push and pull situation.

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Portfolio Management in the Construction Industry – Pricing Strategies Considering the Chance/Risk Ratio for Several Projects

Markus Kummer
(Project Assistant, Graz University of Technology, Graz, Styria, Austria)

Christian Hofstadler
(Professor, Graz University of Technology, Graz, Styria, Austria)

Abstract

The portfolio theory was developed by Markowitz (1952) and was originally a subfield of capital markets theory. Its starting point is a defined available investment amount distributed across several asset classes, such as equities or bonds, by its spreading or diversification. This diversification aims to reduce the associated risk relative to the variance and percentage of the return compared to an investment in only a single asset class. In relation to the capital market, this raises the question which securities to aggregate in a portfolio at which proportions. On the practical level, such an aggregation of investment opportunities happens through the establishment and marketing of funds, such as equity funds.

In practice, theoretical considerations on how to establish an optimal portfolio are compromised by uncertainties of data and information on available investment alternatives as well as by market volatility.

In the construction industry, contractors are faced with a similar situation since they submit bids for various projects or requests for proposals. Contractors use the bid price as the key award criterion and thus manage both the chance/risk ratio in relation to the contract award and the economic success of the project if they are actually selected as the winning bidder.

Contractors thus need not only focus on individual current or new projects; they should also integrate the interactions between these different projects and departments into their considerations. This means that the portfolio approach provides a sound basis for decision-making with respect to the pricing of future projects.

Keywords

management of chances and risks; portfolio management; chance; risk; Monte Carlo simulation; construction contractor; project volume; chance/risk ratio

1. Introduction

In the engineering sciences, the concept of resilience refers to the capability of technical systems to not fail completely in the event of a partial breakdown (Bonstrom and Corotis, 2014). In this sense, any major project that a single contractor or consortium is unable to compensate financially by other projects (or insurance coverage, cf. El-Adaway and Kandil, 2010) constitutes a risk with respect to resilience. If a major project incurs substantial losses, this can pose a threat to the continued existence and operations of the company.

Elements of project portfolio management are utilized to investigate the resilience of a business or of one of its departments in respect of current and potential future projects. In this context, a (project) portfolio comprises a set of projects that are being jointly managed in order to yield a greater benefit for the business or department compared to independently managing each individual project. This exercise aggregates similar projects that can be allocated to a defined part of the organization.

Project portfolio management focuses on projects of a single management unit and deals with the permanent planning, prioritization, overall management, and monitoring of these projects. Key responsibilities include the assessment of future projects and continuous monitoring of current projects as well as tasks related to information and knowledge management across projects. Unlike project management, project portfolio management does not end with the completion of the considered project. Rather, it is a permanent management task that must be repeated in each subsequent cycle.

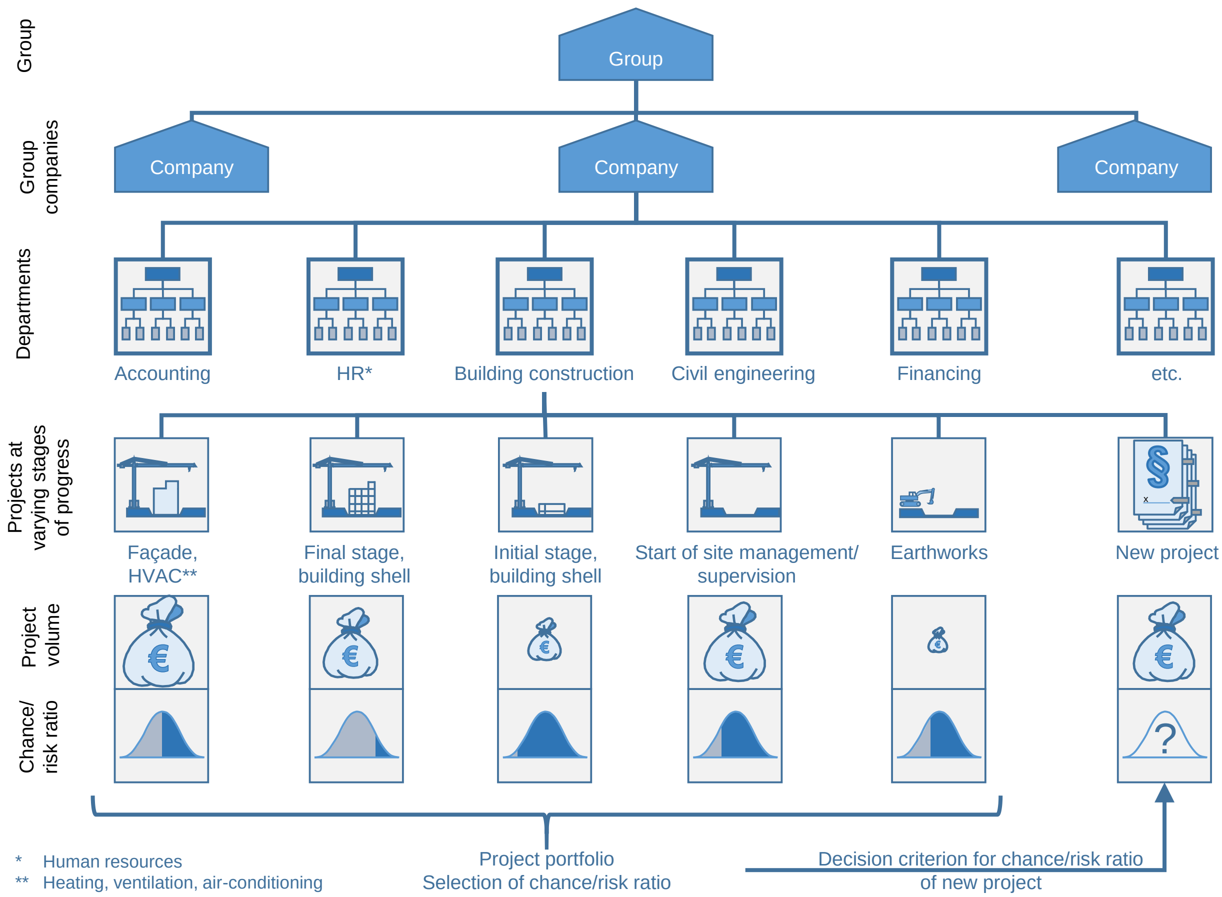

Figure 1: Selecting the chance/risk ratio for new projects

Fig. 1 shows a schematic representation of the structure of a company (or a group of [construction] companies). This company is subdivided into various departments that each manage projects of various sizes (project volumes) and at various stages of progress. In the first step, the chance/risk ratio of the existing project portfolio can be determined if a probabilistic cost estimate was previously performed for each of the projects, or if the chance/risk ratio can at least be stated that was assumed for the individual projects on the basis of the bid price. It is then possible to incorporate the probabilistic cost estimate in the portfolio for each new project and to determine the total marginal bid price from within the given range by performing a reverse calculation or selecting a chance/risk ratio.

At this stage, project portfolio management considers projects managed by identical departments, but it can also be extended towards the top, for instance by forming a portfolio comprised of several departments or companies. In so doing, cost calculations for projects in the execution phase must be continuously updated to enable project-related conclusions regarding the current chance/risk ratio.

2. Modeling

Fig. 2 shows the flowchart developed by Hofstadler and Kummer (2017) that is applied to modeling a portfolio management system that builds upon the chance/risk ratio of individual projects or of the entire portfolio. In the first step, the chance/risk ratio of a project portfolio is determined (control instrument), followed by calculating the bid price of a new project on the basis of a target chance/risk ratio (management instrument).

Initially, all current projects managed by the department or company must be listed with their contract volume or total amount. For projects in later completion phases, the contract amount needs to be adjusted by any quantity over- or underruns and additions to the contract. The total is derived from the deterministic contract volume data. This amount is subsequently used to calculate the chance/risk ratio of the current project portfolio.

Each project needs to be checked with regard to the existence of a probabilistic cost estimate (adjusted to project progress). If such a probabilistic cost estimate is available, it should be directly applied to modeling the cost distribution for the respective project. If no probabilistic cost estimate exists, further information or qualified estimates of the current project situation are necessary. This information comprises potential cost deviations (minimum and maximum values) as well as the probability (expressed as a percentage) of over- or underrunning the (adjusted) bid price. Overall, these two percentages, which reflect the chance/risk ratio for the individual projects, must give 100% (probability and counterprobability). Additional information, such as shape parameters, might be required depending on the distribution function selected for the cost distribution per project (Kummer, 2015).

After modeling all cost curves as distribution functions, a Monte Carlo simulation can be performed to derive the cost distribution total. This addition results in a histogram whose range also contains the deterministic value of the total derived from the contract volumes. The probability of over- or underrunning this value within the range of the derived histogram corresponds to the chance/risk ratio of the current project portfolio.

For any new project that is to be integrated in the product portfolio by submitting a bid, a probabilistic cost distribution must be determined and added up together with the other cost distributions of current projects. This step results in a histogram of the cost distribution within the new portfolio.

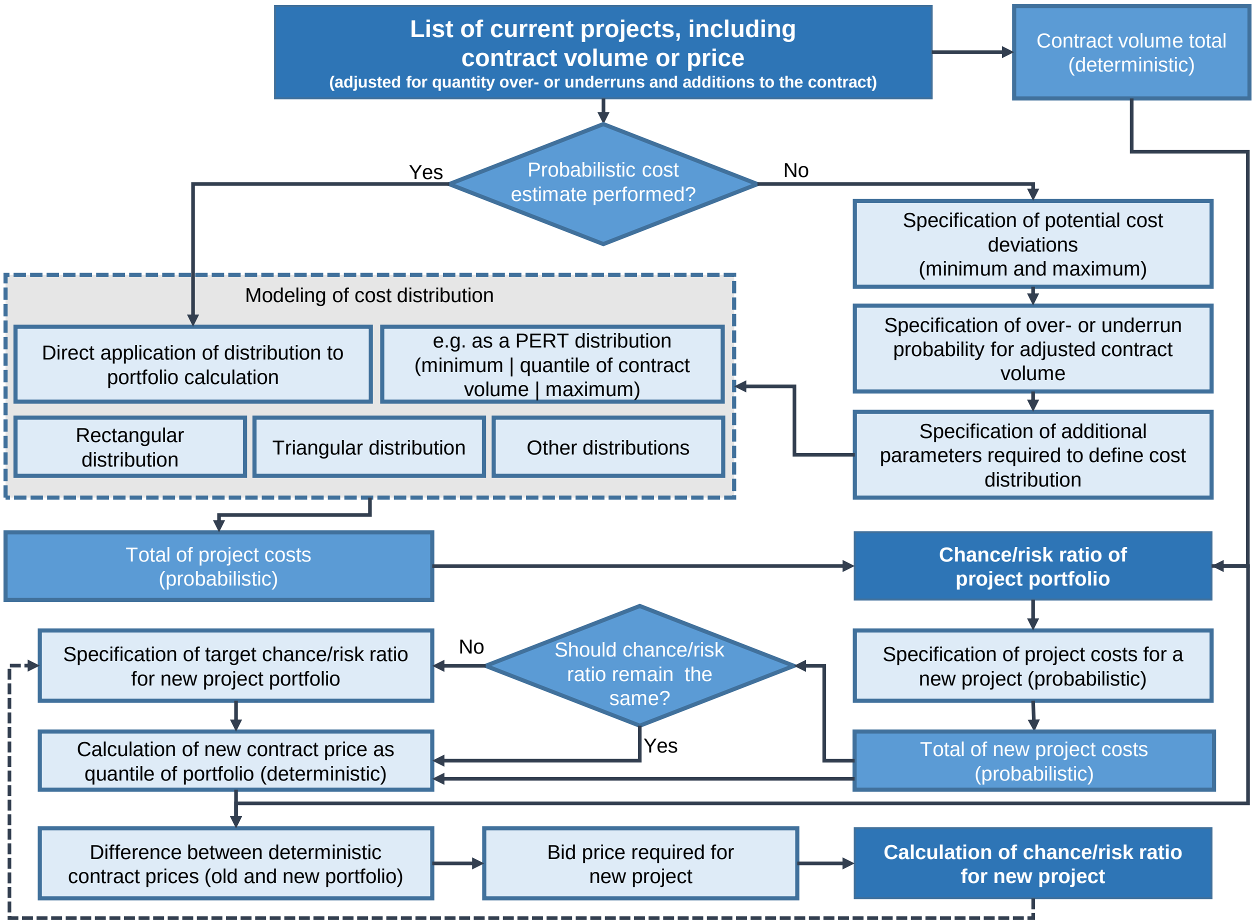

Figure 2: Flowchart – chance/risk ratio – project portfolio

In the next step, a decision must be made as to whether the previous chance/risk ratio should still be used after adding the new project to the portfolio, or whether this ratio needs to be adjusted. If such an adjustment is intended, the new ratio should be stated, and the histogram representing the new total should be used to determine the corresponding quantile of bid prices for the new portfolio.

The difference between the (deterministic) bid prices of the original and the new portfolio results in the (minimum) bid price for the new project required to achieve the risk-diversified target chance/risk ratio for the entire new portfolio.
Finally, entering the derived deterministic bid price into the cost distribution of the new project enables determination of the corresponding project-specific chance/risk ratio. If the derived chance/risk ratio or bid price for the new project is unacceptable, for instance because of an exceedingly high risk for the single project, the target chance/risk ratio must be adjusted for the portfolio, or the project should not be added to the portfolio at all.

3. Worked Example

A worked example (Hofstadler and Kummer, 2017) demonstrates for a corporate department how the chance/risk ratio can be determined for the portfolio of current projects and how a new project can be integrated into the portfolio.
Cells 1 to 5 of Table 1 list currently executed projects with their designations (Column A) and current stage of progress (Column B). Column C specifies the deterministic individual contract volumes or bid prices

(adjusted for quantity over- or underruns and/or additions to the contract). The total of these contract volumes is calculated in cell C6. Thus, the project portfolio is comprised of projects with varying levels of progress and different sizes (project volumes). Likewise, the individual projects are associated with varying chance/risk ratios.

Columns D and F contain the possible absolute cost deviations from the contract volume per project. Contract volumes must lie within the range specified in columns D and F. Columns E and G state the percentage deviations of minimum and maximum values on the basis of the deterministic bid prices shown in column C.

Minimum and maximum values can be used to define rectangular distributions if no probabilistic calculations of cost distributions were performed for the individual projects. Another approach would be to use the minimum value (column D), the contract volume (column C) and the maximum value (column F) to define a triangular or PERT distribution. However, since the contract volume need not necessarily correspond to the expected value (mode) of, for instance, a PERT distribution, columns H and I provide the option to specify probabilities of contract volume over- or underruns. The total of both percentages must amount to 100%. These percentages also reflect the chance/risk ratio of the relevant project. Column J contains the cost distributions of the individual projects. This is where existing distributions derived from probabilistic cost calculations or newly defined distributions, such as rectangular or triangular distributions, can be entered as far as they are available and/or have been updated or adjusted.

In the worked example, PERT distributions determined by the contents of columns C, D, F, and H are consistently used to demonstrate the applied methodology. The function =RiskPertAlt(“min“;D;H;C;“max“;F) is applied to generate input distributions in the *@Risk* software, which is used for the purpose of these calculations. In this exercise, the letters D, H, C, and F correspond to the values in lines 1 to 5 of the respective columns in Table 1. This definition of the distribution by means of a quantile instead of the expected value makes it possible to directly integrate the estimated probabilities for contract volume over- or underruns into the cost distribution. For Project C, the PERT distribution is thus defined using the following command: =RiskPertAlt(“min“;1,100,000;0.10;1,200,000;“max“;2,000,000).

Table 1: Worked example – project portfolio

Item No.	Project designation	Project progress	Contract volume/ bid price*	Potential cost deviations*				Underrun probability	Overrun probability	Project cost distribution
				Minimum		Maximum		Chance	Risk	
		[%]	[€]	[€]	[%]	[€]	[%]	[%]	[%]	[€]
0	A	B	C	D	E	F	G	H	I	J
1	Project A	80,00 %	30.000.000	28.000.000	-6,67 %	32.000.000	6,67 %	40,00 %	60,00 %	30.192.650
2	Project B	60,00 %	15.000.000	12.000.000	-20,00 %	15.500.000	3,33 %	55,00 %	45,00 %	14.814.020
3	Project C	35,00 %	1.200.000	1.100.000	-8,33 %	2.000.000	66,67 %	10,00 %	90,00 %	1.398.542
4	Project D	30,00 %	17.500.000	15.000.000	-14,29 %	21.000.000	20,00 %	35,00 %	65,00 %	17.989.584
5	Project E	5,00 %	800.000	700.000	-12,50 %	1.000.000	25,00 %	50,00 %	50,00 %	805.251
6	**Total**		**64.500.000**					**31,83 %**	**68,17 %**	**65.200.047**
7	Project NEW	0,00 %	10.875.985	9.000.000	-17,25 %	12.500.000	14,93 %	**82,28 %**	**17,72 %**	10.250.000
8	**New total**		**75.375.985**					**48,00 %**	**52,00 %**	**75.450.047**

* Adjusted for quantity over- or underruns and additions to the contract

Cell J6 in Table 1 calculates the cost distribution total of current projects. A subsequently performed Monte Carlo simulation (50,000 iterations; Latin Hypercube sampling) serves as a basis to derive the histogram of the total and to enter the deterministic contract volume total (column C6) (see Fig. 3). For the entire portfolio of currently executed projects (i.e. A to E), a chance of about 32% results for the actual costs being lower than the invoiced contract volume (cell C6). On the other hand, there is a risk of approximately 68% (counterprobability) for actual costs to exceed the invoiced contract volume.

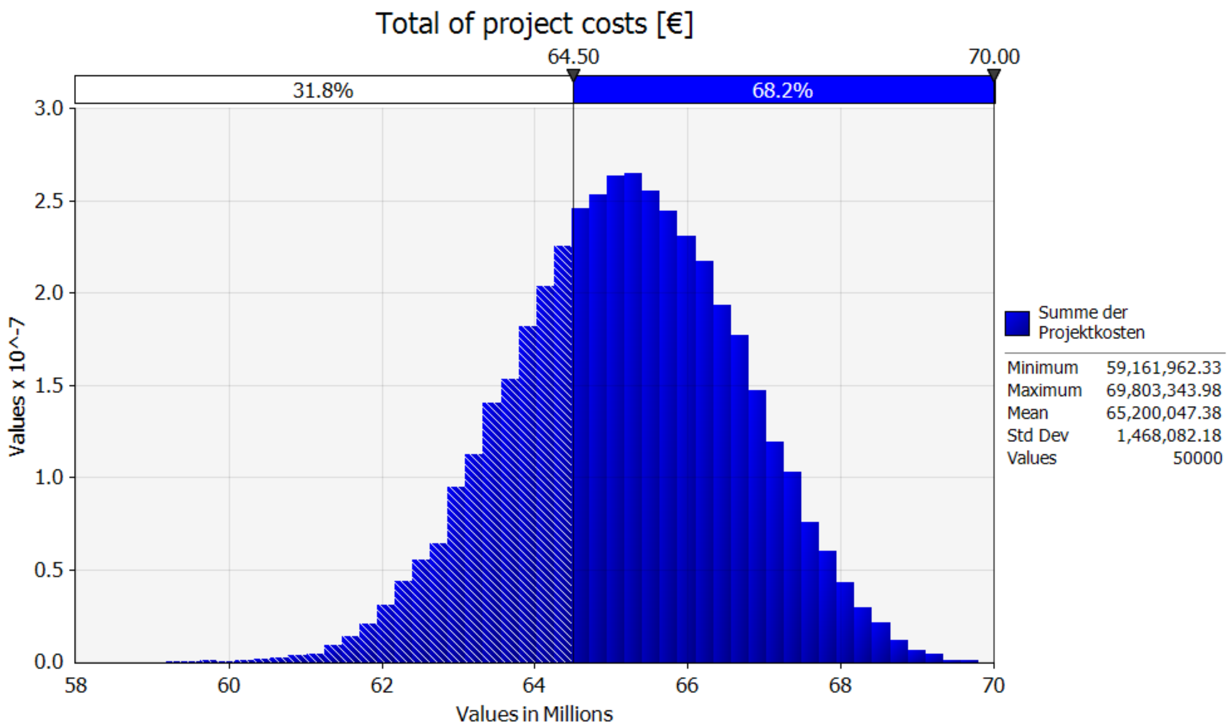

Figure 3: Histogram – cost distribution total (Projects A to E)

The difference between the contract volume total (the deterministic value in cell C6) and the cost distribution total (cell J6) results in a histogram that shows the potential profit or loss relative to the entire portfolio. The amount of the potential profit is represented by positive values on the x-axis, whereas the amount of potential losses is expressed by negative values on the x-axis. In the worked example, the risk of a potential loss outweighs the chance of a potential profit, resulting in an unfavorable chance/risk ratio with respect to the economic success of the department or company. Consequently, this trend should be reversed for any new projects, and the proportion of chances should be increased for the entire portfolio.

The worked example also examines the implications that a new project would have on the chance/risk ratio of the portfolio as well as the bid price that would be required in order to achieve a defined ratio. Line 7 of Table 1 adds a new project to the portfolio ("Project NEW"). For this new project, a probabilistic cost estimate or specification of a cost distribution is assumed. This distribution is entered in cell J7 of Table 1.

A simplified PERT distribution with the following cost values was assumed for the worked example:

Minimum (cell D7):	€9,000,000
Expected value (not shown in Table 1):	€10,000,000
Maximum (cell F7):	€12,500,000

This distribution is subsequently added to the cost distribution total (cell J6) and gives a new total in cell J8. In the next step, the new (target) chance/risk ratio of the new project portfolio (i.e. Projects A to E plus Project NEW) is stated in cells H8 and I8. The total of the two percentages must amount to 100%. In the worked example, a new target chance/risk ratio of 48% to 52% was specified to increase the proportion of chances for the entire portfolio.

Calculation of the 48% quantile of the new cost distribution total (cell J8) makes it possible to derive the deterministic value for the new contract volume total. Fig. 4 shows the new (target) chance/risk ratio for the project portfolio that was set using the sliders. The deterministic value that defines the limits between the two ranges on the upper edge of the diagram is the same as the amount stated in cell C8 of Table 1 (i.e. €75,375,985).

Calculating the difference between the contract volume totals with and without Project NEW (cells C8 and C6) results in the minimum contract volume for Project NEW in cell C7. This total is equivalent to the bid price that must not be underrun on the basis of the probabilistic cost distribution of the new project (cell J7) in order to achieve the target chance/risk ratio for the new portfolio. If a higher bid were placed for the project, this would increase the proportion of chances for the entire portfolio. If a lower bid price were stated, this would increase the proportion of risks not only for the project but also for the complete portfolio. The percentage deviations shown in cells E7 and G7 are related to the deterministic bid price in cell C7.

Finally, cells H7 and I7 are used to state the chance/risk ratio for Project NEW. This step proves that the proportion of chances for this project (with a corresponding project volume) must be defined at a relatively high level (chance: 82.28%; risk: 17.72%) to achieve the intended change in the chance/risk ratio for the entire portfolio. Generally speaking, major projects (with a large project volume) have a more significant influence on the entire portfolio than comparatively small projects. Likewise, the chance/risk ratios of such projects influence the portfolio more strongly than those of smaller projects.

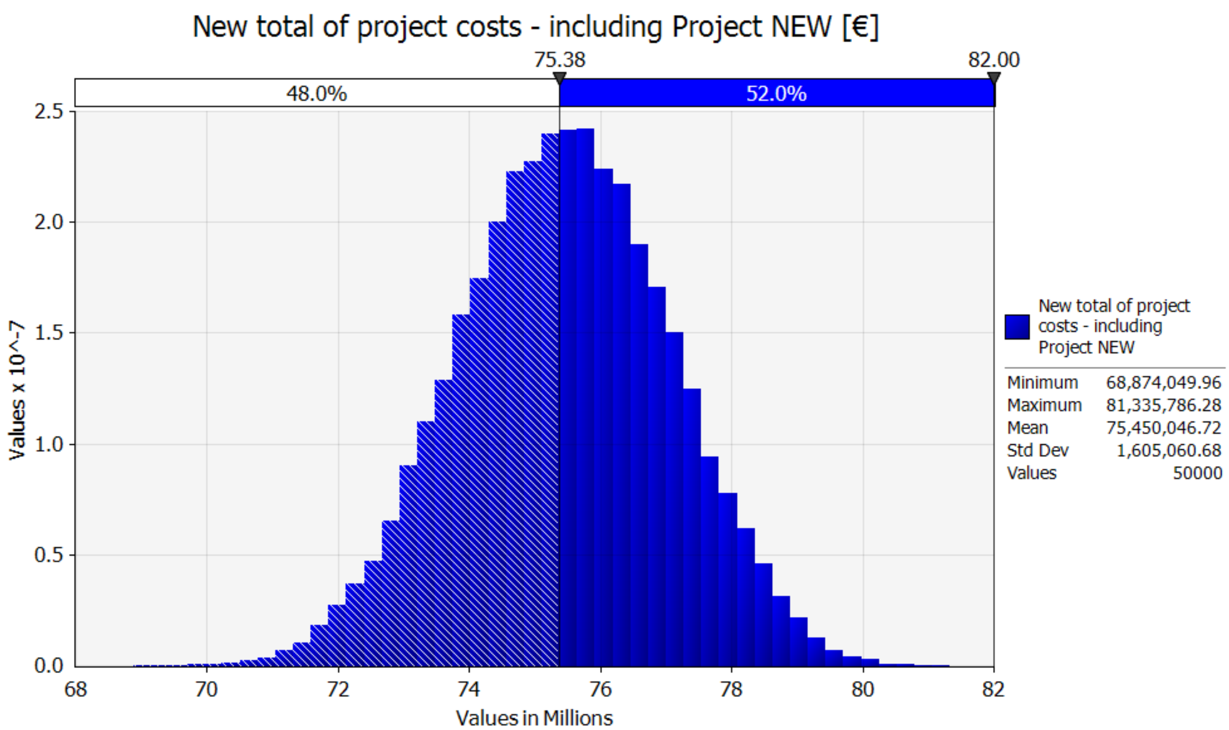

Figure 4: Histogram – new cost distribution total – including Project NEW

The target chance/risk ratio of the portfolio must be adjusted if the bid price determined for the new project using the above approach appears to be exceedingly high (in relation to the market price level). However, the lower the bid price for a new project is, the smaller the increase in the proportion of chances for the portfolio will be. This principle applies until a specific bid amount (marginal amount) is underrun, and the addition of the new project to the portfolio would result in an increase in the proportion of risks for the portfolio.

4. Conclusions

The method of managing and controlling the chance/risk ratio of a full set of current and new projects (portfolio) provides the advantage that bid prices of new projects can be proactively modified in iterative steps if the underlying data base is adjusted accordingly. In this process, the chance/risk ratio determined for the portfolio is used as a key management instrument.

The system outlined above makes it possible to effectively aggregate projects at varying stages of progress, with different contract volumes and chance/risk ratios in a single portfolio, which then permits conclusions regarding individual new projects.

Project portfolio management can thus be used both as a control instrument (monitoring the effects of a selected bid price on the chance/risk ratio of the portfolio) and as a management instrument (determining a minimum bid price to achieve a defined chance/risk ratio for the portfolio).

Clients can apply this methodology in a similar way. Their available budgets only enable completion of a certain number of projects. If no direct returns can be generated on these projects (such as in the field of infrastructure), the portfolio analysis will be restricted to the expense side (expenditure or costs) (see e.g. Dettbran et al. 2005). The client or principal should thus aim to prevent any overrun of the available total budget. However, this goal can be achieved only with a certain probability due to the uncertainties associated with future developments. Clients utilize the selection of projects to be completed or the narrowing of the cost ranges of individual projects (for instance by entering into lump-sum and/or fixed-price agreements) as management instruments. Depending on the type of client (public vs. private), there is a greater or lesser degree of flexibility in terms of project selection. Unlike financial mathematics, which, for instance, enables the purchase of any number of shares, the project portfolio management approach does not enable the “cutting into pieces” of individual projects. Any investment in a project is either effected in full or not at all.

The above model poses the particular challenge of correctly determining the chance/risk ratio for current projects and deriving an appropriate definition of distribution functions in order to arrive at conclusions for the entire portfolio and, subsequently, for individual projects.

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A Review of Hospitals Functional Resilience and Performance Indicators

Farhad Mahmoudi, Sherif Mohamed
(School of Engineering and Built Environment, Griffith University, Queensland, Australia)
farhad.mahmoudi@grtiffithuni.edu.au , *s.mohamed@griffith.edu.au*

Abstract
In order to deliver healthcare services, hospitals' functional performance depend on their physical structure and organisational performance as well as the availability of services which are being provided by the other regional infrastructures. Therefore, any physical damage or functional disruptions can have a negative consequence on their effective response which can worsen the outcome of the emergency situation. In the seminal literature, it has been suggested that further research is needed in order to introduce a unified set of indicators and metrics through which hospitals' sustainable operational performance can be measured. For assessing the extent of vulnerability and resiliency of healthcare facilities, a number of frameworks, toolkits and checklists have been developed by scholars and institutions. Although the indicators and metrics, being used in these tools, have some similarities, they are widely different based on what they intend to measure. This paper reviews the relevant literature and presents a functional resilience index for evaluating hospitals' resilience in face of disruptive events.

Keywords
Hospital, Resilience, Functional, Performance, Metrics

1. Introduction

Hospitals are one of the healthcare facilities delivering healthcare services to the communities they are located in. Furthermore, they have an undeniable impact on the community and the national and regional economy and dealing with the impacts of disastrous events on citizens. However, the effectiveness of their functional performance and response to impacts of disasters can be compromised by any physical damage or functional disruption. In other words, the efficiency of hospitals' functional performance relies on their physical structure, organisational performance and the availability of external services delivered by their lifeline infrastructures and supply chain (Arboleda, 2006). Hence, maintaining hospitals' functional performance is critical in order to continuously deliver healthcare services especially when the community is exposed to disruptive events.

The existing literature states that while risk management practices monitor the adverse impacts of disruptive events and minimize the probability of their occurrence in using different services, products or systems; the concept of resilience focuses on the ways and solutions to reduce the negative impacts and time to recover from such events to their near exposure state (Park et al., 2013). For maintaining hospitals functionality, various factors need to be considered. These factors include: 1) the extent of vulnerability of structural and non-structural components, 2) their critical infrastructure (CI) networks, 3) the potential impacts of events on facilities' occupants, including disruption to staffing, and 4) the role of their external stakeholders and public policies to absorb and response to the adverse impacts. The aim of this paper is to critically review the literature focusing on metrics and indicators through which it is possible to evaluate the extent of hospitals' functional resilience can be evaluated. It also proposes a functional resilience index by which hospitals resilience can be evaluated and enhanced.

2. Literature Review

Maintaining hospitals' functional performance is prone to impacts posed by the occurrence of various types of events such as man-made, seismic or extreme weather events. One of the methods for evaluating the extent of vulnerability/resilience of their operational capacity through which they can sustain delivery of their services is using a number of metrics and indicators. In a broad term, indicators are used for representing measurable quantities. Primarily, indicators were defined in the literature for assessing the system's performance considering sustainable development initiatives. In the context of systems' resilience, the metrics and indicators assist system developers to evaluate the current state of system's resilience in order to evaluate the effectiveness of strategies and practices and highlight the areas need to be enhanced.

The operational aspect of the system is measured against the susceptibility, coping capacity and resilience of a system at risk to an impact, albeit ill-defined event (Birkmann & Birkmann, 2006). Therefore, indicators can be used to measure the effectiveness of hospitals' preparation procedures in order to mitigate and/or deal with the negative impacts of extreme adverse events (e.g. floods, storms, earthquakes, etc.).

Resilience indicators, commonly, evaluate the ability of the system, during the event's adaptive cycle, to absorb and withstand the adverse impacts, effective response and efficient recovery to its near exposure state (Rogers, 2011; Zhong et al., 2015). The resilience metrics consider various factors in the hospitals' hard and soft infrastructure through which the performance of hospitals during disasters can be sustained, such as structural components (e.g. infrastructural safety), non-structural components (e.g. staff capability), emergency medical functions (e.g. critical care, on-site rescue, and surge capacity), and disaster management mechanisms (e.g. plans, crisis communication, and cooperation) (Bruneau et al., 2003; Klein, 2011; Paturaset al., 2010; Zhong et al., 2014). Therefore, the aim of developing resilience metrics and indicators is to help decision-makers to prioritise the resilience practices, raise the organisational awareness and align them with the organisations' overall goals and objectives.

Hiete et al. (2011) assessed the impacts of a power outage on a healthcare care system in Germany for identifying the possible preparation, mitigation and recovery (PMR) measures via analysis of scenarios where the duration of interruptions varied. Mulyasari et al. (2013) developed a "four pillars of hospital preparedness" based on facilities' structural, non-structural, functional and human resources preparedness facing seismic events. Paterson et al. (2014), in a pilot study, categorised indicators into two categories "Emergency Management and Strengthening Health Care Services" and "Climate Proofing and Greening Operations". The indicators in this category divided into a number of sub-categories for responding to different types of perturbation.

In addition to academic publications, the World Health Organisation (WHO) published a series of guidelines and checklists as a management tool for evaluating the preparedness of health facilities for dealing with disasters in different regions. These checklists consider hospitals' functional capacity in responding to emergent events relying on their critical systems, supplies, and disaster management capacities. Therefore, the breakdown in functional capacity of hospitals is considered the main cause for the interruption in hospitals' service delivery at the time of perturbations. The developed checklists are simply questionnaires based on sets of indicators in order to quantitatively measure the extent of healthcare facilities preparedness and vulnerability to various types of disruptive events. These checklists assess hospitals' capability of delivering healthcare services during disasters (PAHO, 2008).

The main purpose of developing these checklists are providing a standard approach for determining the extent of the functionality of hospitals by introducing a set of standard criteria as a basis for reviewing the safety and needs of the facility.

3. Discussion

The objective of this paper is to critically review the available publications with regard to evaluate the hospitals' vulnerability and resilience via a set of metrics and indicators. Reviewing the literature helps to identify gaps, issues and opportunities for further study. In the current paper the reviewed publications, where many attempts have been made to evaluate different strategies and policies to effectively mitigate and efficiently respond and recover from disasters, are grouped under two groups of metrics for "Evaluation of the Current State of Hospitals' Resilience" and "Evaluation of the Resilience Performance", presented in Figure 1. Furthermore, these developed checklists were classified based on the "purpose of their development" and "resilience dimensions" they were covering. In the reviewed literature, often times there were relationships between the purpose of development of sets of metrics/checklists and the dimensions they have covered. These relationships can be explained as;

- Prevention / Mitigation Measures: mainly presented structural and non-structural dimensions which evaluate the inherent characteristics of hospitals infrastructure in order to absorb and withstand the direct/indirect impacts of disasters.
- Preparedness Measures: represented by Functional and Organisational indicators through which the adaptive capacity of facilities can be investigated.
- Recovery Measures: mainly represented by Functional and Organisational indicators which indicate the system's capability to return to an equilibrium state.

In other words, these measures evaluate the current state of physical structures capabilities for absorbing and withstanding the impacts of disasters and investigating the adaptive capacity of facilities which is their organisational ability to respond to adverse impacts of perturbations. However, not many frameworks and practices were considering the measures for evaluating the efficiency and effectiveness of practices in order to recover systems' functional performance to their near exposure state.

Group	Authors	Purpose			Dimensions			
		Prevention / Mitigation measure	Preparedness measure	Recovery measure	Structural	Non-Structural	Functional	Organisational
Evaluation of the Current State of Hospitals' Resilience	WHO/SEARO (2004, 2008)	✓			✓	✓		
	WHO/EURO (2006)	✓	✓		✓	✓	✓	✓
	WHO/WPRO (2006, 2008)	✓	✓		✓	✓	✓	✓
	PAHO (2008)	✓	✓		✓	✓	✓	✓
	CCGHC (2013)	✓	✓			✓	✓	✓
	Mulyasari et al. (2013)	✓	✓		✓	✓	✓	✓
	Paterson et al. (2014)		✓				✓	✓
	Djalali et al. (2014)		✓				✓	✓
	Takim et al. (2016)		✓		✓	✓	✓	
Evaluation of the Resilience Performance	Hiete et al. (2011)	✓	✓	✓			✓	✓
	Zhong et al. (2014)		✓				✓	✓
	Zhong et al. (2015)		✓				✓	✓

Figure 1: Classification of Existing Measures for Evaluating the Extent of Hospitals' Resilience

The primary difference between these developed metrics and checklists can be traced back to the objectives for developing such assessment tools. Relatively, based on the type of the approach to resilience assessment, different scales were identified in order to measure/rate the extent of hospitals' resilience or vulnerabilities. In the first group the checklists, developed by the WHO, CCGHC (2013); Paterson et al. (2014), Djalali et al. (2014) and Takim et al. (2016), can be used to evaluate the extent of current state of hospitals' physical structure being able to withstand disastrous events and organisational preparedness in order to respond to the circumstances arise from such events. These approaches can offer a low-cost screening tool for estimating the probability of the facility remaining operational facing various types of disasters (PAHO, 2008). By considering different types of disruptive events, these tools try to highlight the possible outcomes of every single event and suggest preventive actions in order to mitigate their adverse impacts. Therefore, these tools can be used for two main purposes by considering various aspects of the healthcare facility as a system through which it is possible to screen/monitor the current state of hospitals' safety, vulnerabilities, readiness and resiliency. In other words, they can be used as tools for assessing various aspects in order to address the areas that need to be considered for reducing system's vulnerabilities and enhancing its resilience. However, these sets of metrics and checklists do not consider the dynamic behaviour of the hospital's systems in dealing with the consequences of uncertainties arising from "Unknown-Unknown" situations.

In the second group, which focuses on evaluation of the resilience of hospitals' functional performance, Hiete et al. (2011), and Zhong et al. (2014, 2015) focused on the extent of effectiveness of practices being performed in order to enhance the hospitals' functional resilience. These approaches focused on the process of systems' resilience by enhancing hospitals' infrastructures capability to withstand the adverse impacts of the events and improving the organisational adaptive capacity in order to absorb, respond and recover disruptions. However, regarding indicators, it has been stated that more studies need to address and redefine performance metrics and indicators for maintaining hospital's performance due to the availability of a few number of studies that attempted to define and develop relevant resilience metrics and frameworks (Zhong et al., 2015). The analysis of the literature addressed, Zhong et al. (2014, 2015) mainly focused on the hospitals' organisational preparedness and the capacity to respond to consequences of disruptive events whereas; Hiete et al. (2011) on the other hand, considered hospitals' resilience via their non-structural components in order to mitigate the adverse consequences and organisational preparedness in order to adapt and respond respectively.

Regardless of the purpose of developing metrics and checklists, some areas of improvement have been identified for enhancing hospitals' functional and operational resiliency. It has been highlighted that there is a need for continual reinforcement of functional preparedness and disaster management practices through which disaster management practices and preparedness can be effectively improved (Achour et al., 2016; Djalali et al., 2014; Labaka et al., 2015; Olu et al., 2016; Omidvar et al., 2014; Salevaty et al. , 2015; Tabatabaei & Abbasi, 2016). Specifically, different publications addressed the need for continuous improvement of situational awareness of disaster management committees (Djalali et al., 2014); performing organisational training for emergency drills and practices, develop, update and practice the action plan by hospital disaster committees in order to efficiently respond to the disasters (Achour et al., 2016; Olu et al., 2016; Omidvar et al., 2014; Tabatabaei & Abbasi, 2016). Hence, enhancing the effectiveness of healthcare facilities' resilience practices is a continuous process which involves;

- Increasing the degree situational awareness and commitment.
- Regular staff training and performing emergency drills, and
- Regular revision of resilience practices and action plans.

The other aspect that can impact the resilience of hospitals' performance is considering the participation of their external stakeholders in the event adaptive cycle process (Rautela et al., 2011). It was highlighted that the engagement of external stakeholders in response planning and policy-making procedure can improve the efficiency and effectiveness of response practices and recovery period as well as mitigates the potential overlap or misalignment of operational boundaries among external stakeholders (Loosemore et al., 2013). Geroy et al. (2011) addressed the need for involvement of governments and institutional organisations by developing preparedness, response and recovery plans that can be implemented before and after exposure to an adverse event. Furthermore, the coordination between various agencies and incorporation of disaster management plans in health legislation, policies, and strategic plans have been recommended (Achour et al., 2016; Olu et al., 2016). Specifically, Olu et al. (2016) highlighted the need for well-defined policies and strategies in order to align disaster plans and disaster response management activities with hospitals' technical environments. The main objective for such alignment is to prevent the possible fragmentation in response activities among various agents in order to enhance the responses' effectiveness and efficiency. Hence, there is a need for the involvement of external stakeholders in the events' adaptive life cycle, into account. In other words, in addition to evaluating hospitals capability to absorb and response to the disasters, the effectiveness of external agents' practices, involving in response procedure, need to be addressed and assessed considering the individual hospital goals and objectives as well as the regional and national healthcare sector goals and objectives.

By reviewing the existing metrics and indicators for evaluating the resiliency of hospitals, as well as CI literature, a set of conceptual performance metrics and indicators are introduced in this paper through which the resiliency of hospital's functional performance can be evaluated. The functional resilience index (FRI) is developed based on Zhong et al. (2015) and Labaka (2013) studies in which the various aspects related to hospitals and CI functional performance resiliency are addressed regardless of the different types of perturbations (Figure 2). In the development of the FRI, the internal resilience metrics and indicators are identified and categorised into four dimensions namely, technical, organisational, and economic. FRI is mainly focusing on preparedness and recovery of facilities capturing functional, organisational and economic aspects of resilience, yet not covering structural and non-structural aspects of hospitals infrastructure.

The developed set of metrics can be used to measure implemented strategies and practices throughout the facility for continuously enhancing the functional resiliency of hospitals other than using checklists for screening the current state of hospitals functional performance. Moreover, FRI identifies a set of external divers by which the facilities performance, during perturbations, can be affected. These metrics mainly assess the effectiveness of disaster management strategies among hospitals external agents that are involved in the process of disaster response and recovery. Therefore, FRI can offer a comprehensive set of performance metrics and indicators for assessing the extent of the functional and organisational resiliency of hospitals by considering the activities performed by their internal and external stakeholders' performance.

4. Conclusion

This review paper focused on the publications defining different sets of metrics and indicators in order to evaluate the extent of hospitals' vulnerability and resilience. The developed metrics, indicators and checklists were categorised into two general groups based on the different objectives for evaluating facilities' resilience. These goals and objectives can be evaluation of facilities' current state of resiliency or assessment of the socio-technical capacity of the hospitals to absorb and adapt to uncertainties.

The findings suggested while the extent of the hospitals' resilience can vary based on the type of the events they may encounter with. The majority of publications highlighted that improving the performance of hospitals to deal with disasters is much lower than in other sectors due to lack of organisational preparedness and CI network's response to adverse impacts of disasters. In addition, various areas for improvement have been addressed in the literature with respect to challenges in the healthcare sector faced by policymakers regarding specific types of events. in other words, a lack of consideration in tailoring policies and introducing new strategies and plans was identified in the literature which needs to be addressed in the future studies. Finally, the analysis of the literature highlighted the need for development of more comprehensive set of metrics and their relevant indicators by which the extent of hospitals' functional resilience can be assessed.

INTERNAL RESILIENCE

Technical: Metric	Technical: Sub-Metric	Organisational: Metric	Organisational: Sub-Metric	Economic: Metric
Facility Safety Design and Construction	• Safety systems • Redundancy • Degree of Independence • Audits	*Hospital safety standard and procedures*	• Surveillance • Hospital infrastructural safety and vulnerability	*Crisis Response Budget*
Maintenance	• Preventive maintenance • Corrective maintenance	*Disaster leadership and cooperation*	• Leadership • Disaster cooperation	
Data Acquisition and Monitoring System	• Data acquisition equipment • Information monitoring equipment	*Disaster plans*	• Plan system • Operating procedures to execute the plan	
Crisis Response Equipment		*Disaster stockpiles and logistics management*	• Disaster resources • Emergency Medication	
		Emergency staff capability	• Constitution of emergency group • Staff management	
		Emergency training and drills	• Emergency trainings • Emergency drill	
		Emergency critical care capability	• Disaster surge capacity • Disaster response procedures • On-site rescue • Hospital treatment	
		Recovery and adaptation mechanisms	• Recovery and report	

EXTERNAL RESILIENCE

Organisational: Metric	Organisational: Sub-Metric	Social: Metric	Social: Sub-Metric	Economic: Metric
First Responder Preparation	• First Responder Preparation • First responder situation awareness and commitment	*Societal Situation Awareness*	• Societal situation awareness and commitment • Societal training	*Public Crisis Response Budget*
Government Preparation	• Government situation awareness and commitment • Government training • Government communication capacity • Government leadership capacity • Coordination of the response agents			
Trusted Network Community	• Shared information systems and databases • Trust and engagement of the participants			
Crisis Regulation and Legislation	• Regulations and laws revision and update • Compliance level of regulations and laws			

Figure 2: Resilience Metrics (adapted from Labaka, 2013; Zhong et al., 2015)

Based on the identified gaps in the literature and areas highlighted by scholars, a conceptual functional resilience index is being developed. The primary objective of developing a FRI is to evaluate the resiliency of the current activities and functional performance of hospital's internal and external stakeholders by which resiliency of hospitals functional performance can be achieved. However, the identified metrics and dimensions do not specify which aspects contribute the most to the overall functional resilience of facilities. Hence, in a future study, the proposed index will be evaluated by healthcare experts for introducing a set of critical metrics and activities that contribute the most to the hospital's functional resilience performance.

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A Labor Cost Analysis of the Design Review Process at the U.S. Army Corps of Engineers, Wilmington District Design

Scott Kramer
(Professor, Auburn University, Auburn, Alabama, USA)

Froilán Esclusa
(Graduatte Student, Auburn University, Auburn, Alabama, USA)

Junshan Liu
(Assocaite Professor, Auburn University, Auburn, Alabama, USA)

Abstract

The U.S. Army Corps of Engineers (USACE) mission is crucial to the nation's security and resilience of our infrastructure. As steward of public trust and funding, it is fundamental to design and construct with the highest standards and tradition of quality. The Wilmington District adheres closely and invests significant man-power to comply with a clearly defined guidance for design products quality reviews. Historical project data was analyzed on this research paper with the primary objective of measuring the level of effort invested on design reviews and create a numeric relationship or proportion to the cost increase during construction. This proportion is defined as the Efficiency Ratio (ER); the ratio between the costs of Change Orders per every hour of labor invested in review. The ER is expressed as a decimal number that gives us a graphical representation and attempts to illustrate the level of effectiveness from one perspective. In times of funding challenges and limitations, it is imperative that the distribution of human resources is capitalized and not challenged by it. The conclusions of this analysis provide project teams and management with a tool to prioritize or reallocate resources where the cost benefits and construction cost savings are maximized. Conclusions suggest that resources currently invested in reviewing a certain type of project may be shifted to provide additional review for other type of projects that are resulting in higher changes during construction.

Keywords

Design review, construction labor, USACE.

1. Introduction

The U.S. Army Corps of Engineers (USACE) was founded just a year before the Declaration of Independence and has served our country since 1775. During the early 19th century, Congress and presidents assigned military engineers to such duties as surveying, mapping, locating routes for superintending the construction of roads, canals, and coastal defensive works (http://www.saw.usace.army.mil, 2017). This unique organization is cemented on sound engineering design, construction, and the quality of all its professionals.

In present days, the USACE Wilmington District is tasked with providing design and construction services to the Special Operations Command (SOCOM) residing within the Fort Bragg Army facility in Fayetteville, North Carolina. With approximately 57,000 military personnel, 11,000 civilian employees and 23,000 family members, Fort Bragg is one of the largest military complexes in the world (www.bragg.army.mil, 2017), continuously growing, and requiring the design and construction of new facilities, buildings, and infrastructure upgrades on a continuous basis.

Tasked with such a demanding mission and protective of such tradition and the preservation of its quality principles, the District invests a significant effort, resources, and funding in the quality assurance of design and engineering products. Army guidelines mandate that all design and construction activities intended for contract award follow the process of quality management executed within the District (US Army Corps of Engineers, 2006). The quality management process consists of a series of progressive technical reviews of the design packages performed by internal USACE resources throughout the design stages and at major design milestones and deliverables. The review process is intended to verify the technical completeness and accuracy of the design products and reduce risks of cost, time growth, and unnecessary changes and claims during construction.

The review process is formally documented through comments written by each reviewer at each phase of design. A normal project will produce hundreds or even thousands of comments that must be addressed, discussed, and resolved between the reviewer originating the comments and the designers. The number of comments submitted by each reviewer can be a general indication of the project complexity, but it is also in great part an indication of the level of effort invested by each reviewer to accomplish the review task. The level of effort is translated into labor hours or man-power cost for the District.

There is easily obtainable and accurate data to compare the number of review comments generated per project versus the dollar cost of change orders executed during the construction phase. This data is available for dozens of projects in recent years and for projects of different levels of complexity and construction cost. This comparison will provide a relationship between the labor efforts invested during design phases and the resulting cost of change orders during construction and can illustrate the level of effectiveness from this perspective.

This analysis is based on the reasonable assumption that more review effort and labor time invested on a project during its design phase would result in minimizing the costs of change orders during construction. However, I could not identify a tangible or readily available tool for statistically determining that relationship and if there is a proportional relationship between more labor invested resulting in less change orders.

The objective of this research paper is to sample a significant number of projects to determine the relationship between the number of review comments and the dollar amount of Change Orders. A numeric value designated as the Effectiveness Ratio will be calculated and evaluated for each project type.

2. Background

The review process for USACE is fundamentally based on a regulation defined as BCOES. The purpose of this regulation is to "*establish policy and systematic procedures for conducting effective reviews of a project's Biddability, Constructability, Operability, Environmental, and Sustainability (BCOES) characteristics. These reviews are done during design for a project using the design-bid-build (D-B-B) method or during development of the request for proposal (RFP) for a design-build (D-B) project. The BCOES review results are to be incorporated into the procurement documents for all construction projects."* (US Army Corps of Engineers, 2013)

In compliance with the BCOES regulation, the series of technical reviews performed at the District consists of Design Quality Control (DQC) at every major design milestone and a final BCOES review performed just before the projects are issued for solicitation. This process is performed for all design products that are developed by both USACE internal resources ("In-house") or by contracted A/E firms and that exceed the minimum threshold of $ 150,000 of construction cost. The review process is documented through comments written by each reviewer at each phase of design.

2.1 Design Quality Control Reviews (DQC)

District Quality Control / Quality Assurance (DQC) is the backbone of USACE's quality process. (US Army Corps of Engineers, 2016). Internal technical resources, typically professional engineers and architects, perform this review. For a typical Design-Bid-Build (D-B-B) project where the design is developed on its entirety and of significant complexity, a total of three DQC review efforts are performed. An initial review is performed at the Conceptual/Schematic Phase (35%), a second review at the Design Development Phase (65%) and a third and final at the Construction Documents Phase (95%).

On a Design-Build (D-B) delivery project the District partially develops a design that will be finalized by the awarded D-B Contractor. Two to four DQC reviews will be performed to the design submittals and the Release for Proposal (RFP) documentation depending on the project's complexity. The design contained on a typical D-B RFP package fluctuates between 35% and 65% development.

2.2 BCOES Reviews

In addition to the DQC series of technical reviews, a final review is performed right before projects are solicited for construction. BCOES is defined as Biddability, Constructability, Operability, Environmental and Sustainability. The main objective of this review policy is to *"minimize problems during the construction phase through the effective checks performed by knowledgeable experienced personnel prior to advertising for a contract" and "help to ensure that the government's contract requirements are clear, executable, and readily understandable by private sector bidders or proposers."* (US Army Corps of Engineers, 2013). A fundamental difference between the DQC and the BCOES is that the contract General and Supplementary Conditions (USACE, Contracting Front End) are included in the BCOES package and reviewed by the office of counsel within the District.

2.3 Review Comments Documentation

The USACE utilizes the "Design Review and Checking System" (Dr Checks), a secure, internet-based system to document all review comments originated throughout the process. (East, Kirby, & Kelly, 2001). All comments are entered by the reviewer into the software platform, followed by an analysis and response from the design team and when the comment is clarified and resolved, it is closed by its originator.

The District adheres to this tool for comments documentation. During the design phase, design submittal packages are received by the various teams within the District. Technical resources within those teams evaluate the content of the packages and enter their review comments into Dr Checks. A typical DQC and BCOES review period is open for 1-2 weeks to allow time to the reviewers to evaluate the package and enter comments. After this time window, the review phase is closed and no further comments can be entered until the next design phase review.

Once all the BCOES and DQC comments have been addressed and incorporated by the responsible designer and final resolution agreed with the reviewer, a BCOES Certification, containing a report of all review comments closed, will be signed by the District's Chief of Engineering prior to issue for bid.

3. Data & Analysis

The focus of this research paper is centered in the military mission projects by the USACE at the Wilmington District. All projects analyzed are related to new building construction and maintenance of facilities within that installation and constructed during the past seven years. A total of 40 projects were analyzed and the list was broken down into three types (Type A, B, and C) based on their construction contract amount therefore grouping them into similar scope and complexity, as shown in Table-1.

Table 1: Cost Range of the Construction Project Analyzed in This Research

Projects Type	Construction Cost Range	
TYPE A	$0	$1,000,000
TYPE B	$1,000,000	$5,000,000
TYPE C	$5,000,000	$60,000,000

Three sources of data are gathered, tabulated, and analyzed with the objective of finding relationships and counterbalances between them. This data can be studied by the District's management to better understand the net results and efforts required for the design review process as it is currently executed. The data sources are the following:

3.1 Design Review Comments

The first data obtained was a detailed report from the Dr Checks (https://www.projnet.org, 2017) database containing the number of comments originated for all individual projects identified. Although the comments are broken down by design phase (35%, 65%, 95%, and BCOES), the total number of comments per project was analyzed as one overall figure. The nature and/or technical complexity of the comments are not part of the analysis of this research paper but it is suggested as future research. An overall number of almost 30,000 comments were originated for the 40 projects analyzed, yielding an average of 745 comments per project.

3.2 Change Order Costs

The second data set to compare is the Change Order Costs. The construction contract cost and executed change orders costs for each contract have been obtained for all the projects. Scrutiny was performed to determine that the change orders analyzed are only for changes or modifications during construction and do not include change orders related to previously negotiated alternate items or Bid Options.

The USACE utilizes the Corps of Engineers Financial Management System (CEFMS) (http://www.usace.army.mil/Finance-Center/, 2017) and the Resident Management System (RMS) (http://rms.usace.army.mil/, 2017) which maintain documentation and formalize the financial commitments for every construction contract including all change orders. Data from these two databases was obtained and tabulated to correlate with the design review comments data obtained from Dr Checks. The overall construction cost for the 40 projects analyzed exceeds the $ 500,000,000 with an average of 5-6% cost net increase resulting from change orders.

Table 2 illustrates a tabulation of all the gathered raw data and determines: (A) Average Change Orders / Project and (B) Average Number of Comments / Project

Table 2: Average Change Orders / Average Number of Comments per project

	N	E	F	G	H	A	I	B
					E / N	F / N		I / N
	Number of Projects Analyzed	Total Construction Cost Analyzed	Total Change Orders Analyzed	Increase Cost Percent.	Average Cost / Project	Average Change Orders / Project (rounded $10k)	Total Number of Comments	Average Number of Comments / Project (rounded 10)
TYPE A: $ 1M	10	$5,000,000	$250,000	5%	$500,000	$25,000	1200	120
TYPE B: $ 5M	9	$20,000,000	$1,000,000	5%	$2,222,222	$110,000	1600	180
TYPE C: $ 60M	21	$479,000,000	$29,000,000	6%	$1,380,952	$1,380,000	27,000	1,290
						A		B

3.3 Labor Effort

Lastly, the labor effort for the review tasks was estimated to create a numerical relationship between the costs of labor review and the costs of change orders. The design review process is labor intensive requiring project managers, technical reviewers, managers, customers, and many other stakeholders to invest a considerable effort. Major tasks include not only the actual technical review, but also, management and documentation of the process. Although the labor time invested is directly related to the complexity, how voluminous and familiarity of the reviewers with the type of project, there are administrative tasks and steps that need to be performed for every project creating a baseline labor effort.

Table 3: Estimated Labor Hours per Comment

	Task	Employees	Number of Reviews	Hours per Review	Number of Persons	Sub-Total (rounded)	
TYPE A: $ 1M	Review	Reviewers	2.2	4	4	35	
	Back checks	Reviewers		4	4	35	
	Management	PM		8	1	18	
	Design review meetings	PM + Reviewers		4	5	44	
			Total Number of Hours			132	D
			Average Number of Comments			120	
			Labor Hours per Comment			1.1	C
TYPE B: $ 5M	Review	Reviewers	2.4	8	6	117	
	Back checks	Reviewers		8	6	117	
	Management	PM		12	1	29	
	Design review meetings	PM + Reviewers		8	7	137	
			Total Number of Hours			401	D
			Average Number of Comments			180	
			Labor Hours per Comment			2.2	C
TYPE C: $ 60M	Review	Reviewers	3.4	12	10	411	
	Back checks	Reviewers		12	10	411	
	Management	PM		16	1	55	
	Design review meetings	PM + Reviewers		8	11	302	
			Total Number of Hours			1179	D
			Average Number of Comments			1290	
			Labor Hours per Comment			0.9	C

An average labor effort has been estimated for the design review of each project type (Type A, B, and C) utilizing factors such as: Number of Reviews (35%, 65%, 95% and BCOES), Number of Persons involved in the reviews and Labor Hours per review. Table 3 illustrates the method utilized for the labor estimate and determines: (C) Estimated Labor Hours per Comment.

4. Rationale

The objective of this analysis is to integrate and correlate these three parameters to estimate an Effectiveness Ratio (ER). The ER is formulated as the ratio of how much change order cost is related to one hour of labor invested in the review phase and helps us understand how much review time and labor is currently being invested on a project and what is the return on the investment of that time.

A. Average Change Orders / Project
B. Average Number of Comments / Project
C. Estimated Labor Hours per Comment

EFFECTIVENESS RATIO

= 1*hr of Review Labor: Cost of Change Orders*

= Average Reviewer Salary ($100) / Dollar amount in Change Orders

Table 4: Effectiveness Ratio

	A	B	C	D	E	A / D		E / (A/D)
	Average Change Orders / Project (rounded $10k)	Average Number of Comments / Project (rounded 10)	Labor Hours per Comment	Labor Hours for Review / Project	Average Reviewer Hourly Salary	1 hour of Review	Gvt Pays this $ in Change Orders	
TYPE A: $ 1M	$25,000	120	1.1	132	$100	1 :	$189	0.53
TYPE B: $ 5M	$110,000	180	2.2	401		1 :	$274	0.36
TYPE C: $ 60M	$1,380,000	1,290	0.9	1179		1 :	$1,170	0.09
AVERAGES	$756,250	745	1.4	1053	$100	1 :	$718	0.14

5. Conclusions

5.1 Projects Type A, Construction Cost up to $ 1M

The level of complexity, both in design and construction for this type of projects is limited with a maximum construction cost of $ 1M. The average Change Order per project is $25,000 equivalent to a base contract increase of 5%. An average of 120 review comments are originated and the overall review effort requires 132 labor hours.

The ER for projects Type A is 1: $189, meaning that per every hour invested in review, the District pays 1.89 times this cost in Change Orders resulting on an **ER = 0.53**.

5.2 Projects Type B, Construction Cost up to $ 5M

The level of complexity for this type of projects increases to moderate with a maximum construction cost of $ 5M. The average Change Order per project is $ 110,000 equivalent to a base contract increase of 5%, consistent with Projects Type A.

An average of 180 review comments are originated as compared to 120 for Type A, nevertheless the overall review effort increases from 132 to 401 hours. This is a significant 300% increase in labor hours required for this type of projects. It is acknowledged that this projects type may include more complex features such as complex site work, new primary infrastructure connections, secured facilities/SCIF, more specialized telecommunication requirements, and others that may result in an increase in review effort.

The ER for projects Type B increases from Type A to 1: $274, resulting on a **BR = 0.36**.

5.3 Projects Type C, Construction Cost up to $ 60M

These types of projects are of the highest complexity and number of features. Some of these projects will likely include multiple buildings or facilities therefore a much more elaborate design and construction. The average Change Order per project is $ 1,380,000 increasing to 6% when compared to Types A and B at 5% increase from the base contract.

A staggering increase of 700% in review comments is found when compared to Type B. An average of 1,290 review comments are originated for this Type, illustrating the significant increase in project complexity. The labor hours for review increase to 1179 hours, a 300% increase when compared to Type B.

The ER for projects Type C increase astronomically to 1: $1,170. This proportion is expected to be higher due to the higher costs of construction and for the higher risks of Change Orders due to the size and complexity of these projects.

The ER for these types of projects drops accordingly to just **ER= 0.09**.

- The average ER for all projects combined is 0.14, nevertheless this average is highly influenced by a very low ER for projects Type C and may not be indicative. The average between Types A and B is ER=0.44 and may be more indicative of the true effectiveness.

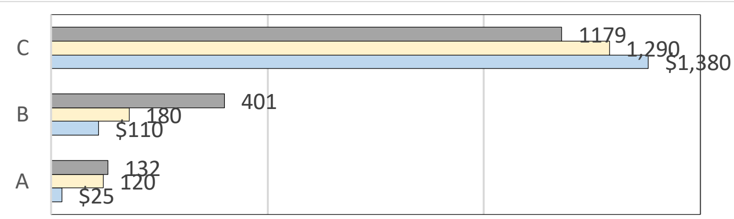
- ER for Type A = 0.53 and Type B = 0.36 reflect a uniform trend reflected as a constant construction cost increase (Change Orders) of 5% for both types of projects.

- The labor effort for projects Type B increases by 300% nevertheless the ER remains reasonably uniform. This is indicative that a substantially higher effort is required to account for the increase complexity in order to maintain the same level of Effectiveness Ratio.

- ER for Type C = 0.09 is below acceptable range and this is reflected as a level in construction cost increase (Change Orders) 6%.

- Analysis may suggest that resources currently invested in reviewing project Types A and B may be shifted to provide additional review for projects Type C where the ER is significantly lower and where there is enormous opportunity for costs savings and Change Order avoidance.

In times of funding challenges and resources limitations within the USACE, the conclusions of this analysis provide project delivery teams and management with a tool to prioritize or reallocate resources where they result in higher cost benefits, or in this case is higher construction cost savings.



	A	B	C
Estimated Labor Hours for Review / Project	132	401	1179
Average Number of Comments / Project (rounded 10)	120	180	1,290
Average Change Orders / Project (rounded $1000k)	$25	$110	$1,380

Figure 1: Labor Hours, Number of Comments and Change Orders Comparison

6. Future Research and Analysis

The topic of this research paper can benefit from future research and analysis efforts. The following areas could be explored:

- Investigate the specific causes or circumstances for change orders and identify by topic. By tabulating the causes of change orders, a trend, recurrence, and vulnerable areas can be identified. The identification of these vulnerable areas can benefit the design and reviewing team as follows:
    - Provide specific and direct attention to those areas during design review
    - Promote labor cost savings by assigning review to less experienced resources (such as recent graduates) that will have a very specific guidelines to follow and not rely entirely on their experience. This will guarantee that these areas are reviewed and provide developmental experience

- A tangible tool can be developed in the form of checklist or a simple computerized application to facilitate the work of reviewers and guarantee that those vulnerable areas are reviewed

In final conclusion, the analysis performed on this Research Paper is not intended to pass judgement on the review process or how it is being implemented at the Wilmington District, but rather provide project teams with a graphical representation of what the review process entails in terms of effort versus value. Also the future research identified could be a potential positive impact to the Districts continuous process of quality improvement.

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Impact of Lean Principles on Timely Project Completion

Helena O'Connor, CAU-RJ, LEED AP, and Khalid Siddiqi, PhD
Kennesaw State University
Marietta, GA 30060

Lean ideas have been used in the business world for some time. Lean advocates have been adapting these principles to different industries, including construction. The main Lean principles are value added to the customer and elimination of waste. It is very important for the owner to get the project completed on time, but that is a contractual requirement. Minimizing time waste and delivering projects "ahead of schedule" would be an *added value* to the customer. Some construction companies have successfully adopted Lean principles to manage their projects while others have not. The objective of this study is to determine the impact of Lean principles on timely completion of construction projects. In this study, projects with Lean strategies versus Non-Lean strategies were compared to analyze the impact on their completion schedule. A survey was conducted with project managers of construction companies to collect data on project completion and which Lean tools have been used. Results indicated that Lean principles application assisted contractors to complete projects ahead of schedule, or helped them catch up to finish on time when delays were encountered. This study is intended for those general contractors who are still skeptical about Lean practices and would like to see examples that Lean can help them deliver projects faster and more efficiently.

Key Words: Lean Principles, Lean Construction, Lean Tools, Lean Project Delivery, Project Completion.

Introduction

Lean principles have been used in the business world for some time. It started in Japan, in the manufacturing floors of Toyota. Since then, professionals from different industries, including construction, have turned to Lean strategies hoping that these ideas can make their business processes and outcomes better. Since not all industries are the same, these Lean principles had to be adapted to each industry peculiarities. The Lean Production five principles are: Specify Value; Identify Value Stream; Make Value Flow; Let Customer Pull Value; Perfection pursue. (Womack & Jones, 1996). From these five principles we can infer that Lean thinking main points are maximizing value and minimizing waste.

In construction, "the critical starting point for lean thinking is value." (Herrala & al., 2012, p. 1). Construction waste related activities are the ones that mostly waste time. "One type of it is response latency, the lag time from a participant asking a question to receiving an answer that is good enough to enable further work." (Koskela & al., 2013, p. 11).

Our motivation was to show contractors that they can deliver projects more efficiently to avoid liquidated damages and be more profitable. Studies suggest that the application of Lean principles to manage construction projects is the answer to accomplish this goal. "The theory and principles drawn from Lean Production seem to be best suited for project management. Promising results in this regard have been reached already in one project management area, namely in Lean Construction." (Howell & Koskela, 2000, p. 8).

The objective of this study is to determine the impact of Lean principles on timely completion of construction projects. A survey requesting the same information on Lean and Non-Lean projects was sent via email to Project

Managers employed by various construction companies in the United States in order to answer the hypothesis that application of Lean Principles does help contractors to deliver projects ahead of schedule.

Results indicated that 62% Lean projects were completed ahead of schedule, as opposed to 24% Non-Lean projects. We conclude that Lean principles and tools application in a construction project help contractors deliver projects ahead of schedule.

We recommend further studies encompassing a larger sample of projects within different US States and other countries to validate even more the benefits of Lean Construction.

Lean Construction

Lean construction is a "way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value." (Koskela & al., 2002, 211). From an owner's perspective, the project has value when is of high quality: meets the owner's program, is within budget, and finishes on time. But finishing on time is a contractual obligation punishable by liquidated damages, not an added value. "Time limits stated in the Contract Documents are of the essence of the Contract. By executing the Agreement the Contractor confirms that the Contract Time is a reasonable period for performing the Work." (AIA A201; § 8.2.1). "The physical goal of the design and production process is a product with value for the customer." (Koskela & al., 2013, p. 9). Adding value is of the essence of Lean construction. In order to create *added value*, the project should then be completed *ahead* of time.

Methodology

This study is founded in the following hypothesis: Application of Lean Principles does help contractors to deliver projects ahead of schedule. Delivering a project earlier means that less time was wasted during the construction process and it is obvious that earlier use of facility is an added value to the owner. Lean construction adepts are utilizing Lean tools in their project management to achieve this goal.

In order to answer our hypothesis, a survey was sent via email to Project managers employed by various construction companies in the United States. We chose to contact project managers because they are the leaders of project delivery and decide on which management techniques to be used by the project team.

We sent out 64 surveys and received 13 responses, yielding information on 34 projects total. The same data for Lean and Non-Lean projects were collected, compared and analyzed. Information was collected on project type, square footage and location, if projects were Lean or Non-Lean, if project completion was delayed, on time or ahead of schedule, what kind of Lean tools were used, if Lean tools were used alone or simultaneously, and if project managers' experience with Lean was positive or negative.

Results

For the purposes of this research, we consider *Lean* every project that used at least one Lean tool, even if not using a Lean contract, or if Lean practices were not adhered companywide. Information on 34 projects has been collected, with a total of 13 Lean projects and 21 Non-Lean projects.

Lean

Out of the 13 Lean projects, 8 have been completed ahead of schedule (62%), 5 have been completed on time (38%), and no project has been delayed (0%). Project Managers stated that 3 out of 5 projects completed on time because

Lean practices were in place and helped project teams to absorb delays (weather and unforeseen hazardous material abatement).

Non-Lean

Out of the 21 Non-Lean projects, 5 were completed ahead of schedule (24%), 14 were completed on time (67%), and 2 were delayed (9%). Project managers stated that 2 out of 14 on time projects required lots of overtime to catch up and finish on time, and owners were not happy.

Table 1

Lean X Non-Lean Project Totals

	Total	Ahead	On Time	Delayed
Lean	13	8 (62%)	5 (38%)	0 (0%)
Non-Lean	21	5 (24%)	14 (67%)	2 (9%)

Lean Tools

Lean construction emerged since projects have become more complex, uncertain, and dynamic, and Lean tools have been developed in response to challenges. *The Last Planner System* was created to address workflow unpredictability. *Pull Planning* was developed to address rarely accurate CPM schedule. *Integrated Project Delivery* began to try to overcome contract boundaries. *Target Value Design* increases collaboration among project participants (Alarcon & al., 2013). *Integrated Concurrent Engineering* can reduce response time significantly (Chachere & al., 2009). *BIM* allows for better project coordination, clash detections and future use by maintenance teams. *Lean Project Scheduling* promotes better team communication and empowerment. *Choosing By Advantages* standardize the decision making process (Rubrich, 2012).

Table 2

Lean Tools Used by Project Managers:

Lean Tools	Number of PM's that Used these Tools
The Last Planner System	8
Pull Planning	5
Weekly Work Plans	5
Daily Stand Up Meetings	5
Constraint Log	2
Percent Progress Complete	2
IPD Contract	2
Project Website	2
Hyperlinked Drawings	1
BIM	1
Digital documents	1
Digital plan kiosk / tablets	1
Profit Sharing with Subcontractors	1
Design Assist	1
Direct Communication with Designers	1
Choosing by Advantages	1
Big Room	1
Visual Control	1

5S	1

Lean Tools Utilization

On a simulation of a structural steel erection project, was found that applying Lean principles simultaneously significantly improved performance (Al-Sudairi & al., 1999). All projects that finished ahead of schedule utilized several Lean tools simultaneously. Although two respondents said that they noticed performance increase even by just utilizing one Lean tool, these projects were on time, not ahead. The three Lean projects that finished on time after hitting delays also utilized several Lean tools simultaneously.

Project Types

Data collected shows that Lean Principles can be successfully applied to multiple project types. Lean project types collected were: 6 Healthcare, 2 Government, 1 Correctional Facility, 1 Multifamily, 2 K-12, 1 Higher Education. Non-Lean project types collected were: 9 Healthcare, 6 Higher Education, 2 Multifamily, 2 Office, 1 K-12, 1 Mixed Use.

Table 3

Lean Project Types and Completion

Lean Project Types	Completion
Healthcare	Ahead
Healthcare	Ahead
Healthcare	Ahead
Healthcare	On Time
Healthcare	On Time
Healthcare	On Time
Government	Ahead
Government	Ahead
Correctional Facility	Ahead
Multifamily	Ahead
K-12	On Time
K-12	On Time
Higher Education	Ahead

Lean Projects Sizes

Project size was not a factor in terms of completion schedule for Lean projects. Lean assisted early completion of projects of a variety of square footages, ranging from 10,000 to 530,000 square feet. Non-Lean project sizes ranged from 13,000 to 2,100,000 square feet. Further studies should be done on larger Lean projects to assess their timely completion.

Table 4

Lean Project Square Footages and Completion

Lean Projects Sq. Ft.	Completion
10,000	Ahead

10,000	Ahead
10,000	Ahead
34,000	On Time
56,000	Ahead
56,000	Ahead
67,000	On Time
75,000	On Time
200,000	Ahead
205,000	On Time
400,000	On Time
450,000	Ahead
530,000	Ahead

Project Locations

All projects analyzed were located in the United States, specifically the following States: Arizona, Florida, Georgia, North Carolina, South Carolina, Virginia, and Wyoming. Further studies should be done comparing completion schedule data of Lean and Non-Lean projects on each State in the USA to account for different regional peculiarities. Other countries are also encouraged to pursue similar studies.

Project Managers Lean Experience

In the survey responses, we also found valuable input on project manager's experience with Lean. All project managers described their experience with Lean as ***Positive***, except one person who described as ***Neutral*** because "despite the tools, Lean culture and behaviors never fully developed".

After analyzing responses, we offer a list of what composes a ***Positive*** experience below and relate that with current theory. All experience elements fall within the "four elements that can be used to fill in the cultural framework and affect culture change in an organization: leadership, communication, empowerment, and teamwork." (Rubrich, 2012, p. 96); and within the Five Big Ideas developed by Lean Project Consulting: "Collaborate, really collaborate; Increase relatedness among all project participants; Projects are networks of commitments; Optimize the project, not the pieces; Tightly couple action with learning." (Forbes & Ahmed, 2011, p. 68). It is important to note that "the observation of the foregoing principles facilitates the deployment of Lean design and construction." (Forbes & Ahmed, 2011, p.69).

Leadership, Trust, and Collaboration. "The most powerful lean technique is the ability to create a culture of trust and collaboration on a project. The success of the tools hinge on the project's culture. If the project leaders can successfully build trust between all team members, then the positive impact of lean will be multiplied. Conversely, if trust does not exist, the team members will revert back to old habits."
A study suggests that leadership is a cornerstone to Lean implementation. "First, managers need to be committed to learning and understanding what it means to become lean and to changing their own behavior accordingly. They have to set an example and ensure a buy-in among people. Secondly, management needs to provide adequate resources to support a cultural transformation." (Pekuri & al., 2012, p. 6).

Easier Management. "Once everyone was committed to the process it seemed to make the job easier to manage."

Enhanced Team Work. "Team members were pulling for each other rather than fighting each other." / "I appreciated the subcontractor interaction and cooperation." According to Forbes & Ahmed, "Projects are a collaborative enterprise." (Forbes & Ahmed, 2011, p. 67).

Enhanced Team Accountability. "Subcontractors worked well together and took accountability for their commitments during pull plan sessions. Allowing them (subcontractors) to have input (in the schedule) made them more accountable." According to Rubrich, "Lean drives down the authority, responsibility and accountability to the lowest levels in the organization." (Rubrich 2012, p.114).

Early Identification of Issues. "It brings issues to the surface way before they start affecting schedule." / "You proactively find the problems earlier, so you can help manage the design team and owner to come to resolution on these items."

Better Coordination and Work flow. "It also helps plan work more effectively and efficiently by allowing trades to look ahead so they can ask the right questions in advance." A study suggests that "measuring and improving planning system performance is the key to improving work flow reliability." (Howell, 1999, p. 7)

Ability to Catch Up. "Lean allowed us to absorb these delays and finish on time." A study states that "Managing the interaction between activities, the combined effects of dependence and variation, is essential if we are to deliver projects in the shortest time." (Howell, 1999, p. 5).

Proven Satisfaction. "I was very skeptical when I first learned about it, now that I have experienced it, I am sold. It changed my way of managing a project permanently." / "I will not do any project the traditional way again." / "It was my first experience, but I won't do another job without using the lean tools we implemented on the project."

Obstacles to Lean Implementation

One obstacle identified was getting architects and owners on board with Lean and timely decisions. But that needs to happen since "there is a need for drastic improvement within the design and construction industry. Industry participants can no longer afford to sit idle wondering whether Lean is a good idea. They must ask "What happens if Lean is not adopted?"." (Naney & al., 2012, p. 2).

Conclusion

Since Lean ideas have emerged, professionals from different industries, including construction, have been studying and seeking how to apply this concept to their industries. Several construction companies have embraced the Lean culture and have been using Lean principles and tools in their project delivery.

The objective of this study is to determine the impact of Lean principles on timely completion of construction projects. After analyzing survey results, we conclude that managing construction projects by applying Lean principles does help contractors to deliver projects ahead of schedule. A few contractors also mentioned that Lean strategies already in place helped their team to catch up and finish on time after suffering delays. In addition, we found that almost all project managers of Lean projects categorized their experience with Lean as positive, with successfully implementation of Lean principles as suggested by current theory.

This research is relevant because it demonstrates that Lean principles can provide added value to the owner, and its applicability in construction is advantageous to contractors. Many professionals are still skeptical about Lean thinking and Lean tools, but results indicate that Lean projects are more likely to finish ahead of schedule than Non-Lean projects, helping contractors to be more efficient and profitable.

We recommend that further studies be done to add rigor. Larger sample of data on project completion of Lean and Non-Lean projects should be collected and compared for different states, and countries. Based on how a positive experience can be achieved, we also recommend that construction companies embrace Lean principles application based on current established guidelines for Lean implementation. Further studies on Owner and Team Satisfaction is also encouraged.

Lean is an important topic in our industry that needs to be embraced by all stakeholders, so we can achieve better project delivery.

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An exploratory study of mentoring in infrastructure development of new entry graduates in the South African construction industry

Morena William Nkomo
(PhD Candidate, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Wellington Didibhuku Thwala
(Full Professor, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Clinton Ohis Aigbavboa
(Associate Professor, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Abstract
South Africa is once again on the brink of a massive growth and development opportunity with the Government's planned 20 year National Infrastructure Development Plan (NIDP) and the 18 Strategic Integrated Project (SIPS) groups that go with this. Mentoring is important for all new entry employees entering the workplace. In spite of the growing research on both sets of individuals, mentors and protégés, mentoring from the perception of the organizational remains comparatively under described. The purpose of this paper is to investigate the impact of mentoring, on graduates employees in the construction industry. Furthermore it will classify the drawbacks, benefits and look at imminent prospects of formal mentoring in medium sized and large organizations in South African construction industry. The paper emphases on how organizations view mentoring. The study was mainly a literature review with a distinct focus on formal mentoring programs on graduate's employees. The data used in the report was mainly qualitative, grounded on the, case studies and historical data. The review is into formal mentoring of graduate's employees entering the work place. The scope of this review is limited to the literature that discusses formal mentoring internal to the workplace which support on and off job learning of new entry employees. The findings revealed the organization current situation and the issues that are vital to the HR function. Mentoring is primarily used to transfer implicit knowledge from those near retirement to younger employees, substitute the personnel development and create well-being at work. Career advancement and work performance are not as important as might have been thought. Young graduates employees, in particular may petition the use of social media, alongside mentoring.

Keywords
Construction industry, Formal mentoring, Infrastructure Development, Human resource development.

1. Introduction

The Scarce and Critical Skills and Knowledge required achieving these momentous development plans have been divided between a vast arrays of occupational workgroups. Integrated workplace learning and graduates training has been identified, not as a "nice to have" initiative, but as a compulsory commitment from organizations that seek to participate in these huge opportunities. Many large and medium sized organizations institute a system of mentoring where an experienced worker passes on her knowledge and expertise to a less experienced worker. In some circumstances, a mentor may be assigned by management or a mentoring relationship may occur in an informal manner. Structured knowledge mentoring has been identified as a preferred methodology for achieving the measured, managed and monitored requirements of integrated workplace learning and graduates training in infrastructure development.

Valuable lessons have been learned from our most recent build programmes, such as the 2010 World Cup stadiums, King Shaka International Airport, Medupi Power Station and Gautrain. Infrastructure investment is a key priority of both the National Development Plan and the New Growth Path. Providing infrastructure for the economy and communities is one of the main ways South Africa will realize inclusive and jobs-rich growth. Quality, affordable infrastructure raises economic productivity. While mentoring can offer many advantages, some possible drawbacks merit attention. The young employees of today are the future business leaders of tomorrow .As generations age the more experienced workers leave the company to younger employees, young graduates entering the workplace after, completing their degrees in higher institutions of learning, who take their place, but with such a large generation such as the Baby Boomers. Young people graduate employees are armed with academic knowledge and enthusiasm, however, many people quickly realize that they lack the skills required to navigate and succeed in a corporate environment. Through the National Infrastructure Plan social partners develop the capacity and skills required to meet the demands of South Africa's growing investment programme, for instance revitalisation of public hospitals and other health facilities, national school build programme, and higher education infrastructure, water and sanitation infrastructure. There is a shortage of professionals, engineering, build environment, limited knowledge retention etc. The size and scope of the 20 year infrastructure development plan justifies the need of skills development and transfer of knowledge from senior employees to junior employees, this can be achieved by effective mentoring of graduates employees in the construction industry (Presidential Infrastructure coordinating commission report, 2012).

1. **Purpose of the Study**

The aim of this paper is to investigate the impact of mentoring in the construction industry. This study will meaningfully contributes by sharing the wisdom and knowledge of transition to retirement employees to ensure corporate knowledge does not simply walk out the door, sharing the collective wisdom and knowledge of the build environment business, linking the corporate and not for profit sectors in a cost effective and meaningful way to share skills, knowledge , and experiences., it will help to steer the course of cultural or other forms of change in an organization through the use of peer mentoring circles for frontline managers responsible for change. Research has shown that individual characteristics such as personality are strong predictors of job-related attitudes and performance (Grant &Wrzesniewski, 2010).

2. **Objectives of the study**

- To investigate the impact of mentoring, on graduates employees in the construction industry.
- To identify the benefits and drawbacks of mentoring from the large and medium sized organization's perspective.

1.3 Methodology

The study is mainly a literature review with a special focus on formal mentoring current situation and the prospects for the future. The data used in the report is mainly qualitative, based on the content analysis, case studies and historical data.

2. Literature review findings

Mentoring is usually a formal or informal relationship between two people a senior mentor (usually outside the protégé's chain of supervision) and a junior protégé. Mentoring has been identified as an important influence in professional development in both the public and private sector in large and medium sized organizations.Mentoring as a form of strategic human resource management is an interesting addition to the HRD literature because it provides a mechanism of change for individual employees, within construction organizations. Having a powerful human resource development (HRD) organization is a worthwhile asset of companies, and an enterprise's efficiency is closely connected to human capital's managerial and developmental systems (Latagana, Dinu & Stoica, 2010). Mentoring is about skill development and specialized knowledge transfer. Mentoring has been used for centuries as a way of helping younger protégés to advance, and, according to Darwin (2000) mentoring is presently at the forefront of strategies to improve workplace learning. Workplace mentoring is the most critical factor in worksite learning.Within the government and the private sector, mentoring is often a component of different types of development, including graduates career development and training programs in large and medium sized organizations. The major function of mentoring within these programs is to promote the protégé's development in specific areas and to facilitate successful completion of the program. While these mentoring relationships can produce positive developmental and organizational outcomes, both mentoring programs and relationships sometimes fail due to a diversity of causes and problems, for example lack of participation, no leadership involvement, poor planning, unrealistic expectations, and unclear goals.

Mentoring in the construction industry is a key element in construction work (Rogers, 2007). For example, it is very common on construction jobsites to have experienced workers, who oversee and mentor less experienced workers. However, the relationship between a mentor and his/her protégé´ in the construction industry may be different from the mentoring relationships typically observed in other industries, due to constantly changing work environment and crews, diverse and rapid tasks, and the short-term relationships that protégé's have with their mentors (Ringen *et al.,* 1995). Jobs in the construction industry can last from a few days to a few years, so the length of any mentor-protégé´.

2.1 Future prospects of formal mentoring in large and medium sized organizations

More and more organizations are creating formal mentoring programs for various reasons. From increased morale to increased organizational productivity and career development, the benefits of an organization that actively supports mentoring are many. However, successful mentoring programs do not just happen. Organizations must first make a strong business case to establish why the organization should dedicate the time, attention and resources required to make a formal mentoring process work. Reasons for forming a mentoring program must be connected to the organization's business goals. Listed below are some reasons why organizations choose to establish mentoring programs.**Career Development** - mentoring helps employees plan, develop, and manage their careers. It also helps them become more resistant in times of change, more independent in their careers and more responsible as self-directed learners.**Leadership and Management Development** - mentoring encourages the development of leadership competencies. These competencies are often more easily gained through example, directed practice or experience than by education and training only. **Knowledge Management or Knowledge Transfer** - mentoring provides for the interchange or exchange of information or knowledge between members of different organizations.

The construction industry has been considered to be one of the most dynamic and complex industrial environments (Druker, White, Hegewisch, & Mayne, 1996). It is a project based industry within which individual projects are usually custom built to client specifications (Loosemore, Dainty, & Lingard, 2003) . Raiden et al.(2001), found that the companies demonstrated significant commitment toward strategic HRD with the benefits of staff retention and improved organizational performance. Staff retention is a problem in the construction companies as young employees are job hopping, due to exposure to new opportunities and greener pastures to some other organizations. On the other hand, the success of an organization, particularly a construction organization, is largely dependent upon the quality and morale of its people (Clough, et al. 2000). HRD provides an influential approach to the development of employees in many business sectors, including the construction industry.

2.2 Benefits and drawbacks of formal mentoring in large and medium sized organizations

It becomes difficult to discuss the benefits of mentoring in large and medium sized organizations, because formal and informal mentoring can be experienced quite differently. Mentoring of young employees is a way senior employees can help drive success of a corporation or an initiative. The young employee may feel the mature employee is stuck in their ways and unwilling to try an alternative, and the mature employee sees the youthful exuberance as flighty and undisciplined.

Numerous positive individual outcomes may be expected from mentoring. Mentoring is usually divided into three separate, but related dimensions, which are career development, psychosocial support and role modeling (Scandura, 1997). Younger protégé's are more likely to receive more role modeling than older ones (Finkelstein et al., 2003), and increased respect for a mentor as a role model may noticeable itself in the protégé's positive attitude to work (Scandura, 1997). Structured mentorship offers various benefits. According to Marsh (2012:6) these benefits can either be directed towards the organization or the individual within the organization. Marsh goes further by listing the following organizational benefits: Increased ability to attract, develop, motivate and retain quality employees. Improvement of succession planning and talent management within the organization.

2.3 Drawbacks

Murphy (1996) in a study of middle aged male mentors classifies benefits that can be associated with mentoring. However, he also talks about the 'shadow side' of mentoring and uses such brands as 'the pain of fractured trust', 'the pain of letting go' and 'the pain of disappointment'. Douglas (1997) supports the views of Long (1997.From the protégé's point-of-view, a negative mentoring experience can branch from a dysfunctional relationship with the mentor (Simon and Eby, 2003), which easily leads to unmet prospects, carelessness and structural separation (Eby and Lockwood, 2005). Overall, mentor-protégé´ mismatches and inadequate relationships seem to be the most established problems in mentoring for both mentors and protégé's (Eby and Lockwood, 2005).

2.4The impact of mentoring on graduates employees within organizations

Though viewed as a key aspect of mentoring (Stephenson, 1998), knowledge transfer has been primarily examined at the interim level (Szulanski, 1996), at the interdepartmental level (Berta & Baker, 2004), and at the team level (Gibson, Waller, Carpenter, & Conte, 2007). Grover and Davenport (2001) suggest that much research on knowledge transfer has a more macro focus, examining the transfer of knowledge between and within organizations. Knowledge management articles highlight knowledge transfer as a key mechanism for organizational success, yet a gap exists between practice (Buckman, 1998) and formal research (Gallupe, 2001; Grover & Davenport, 2001).

Mentoring encompasses coaching, sharing perspectives, and transferring knowledge and wisdom to the mentee(s). The mentor is not a supervisor but a person with whom the employee can communicate freely and honestly without concern about being evaluated. Knowledge transfer is defined as an exchange of organizational knowledge between a source and a recipient (Grover & Davenport, 2001) in which the interchange consists of information and advice about resources and relationships. Tacit knowledge, as originally defined by Polanyi (1966), is the knowledge of "…more than we can tell" (p.4). In contrast to explicit knowledge which can be clearly stated, tacit knowledge is highly personal and embodied in one's experiences, perceptions, judgments, and intuitions.

2.4.1 Mentoring saves money, retains workers, builds leadership, and growth talent

Mentoring contributes to employee growth and tenure. In the long run, a well-organized and managed program can save the company thousands of rands. **Reduced turnover and recruiting costs.** Mentoring relationships can help retain talented people because they have a stronger commitment to the organization (Jacka and Quin, 2010). **Assistance in transferring knowledge from the retiring workforce to new workers.** Many mentoring relationships help younger employees learn from those who will retire soon. Pairing junior staff with more senior staff can reinvigorate the enthusiasm of senior employees as they transfer crucial knowledge to the next generation of workers. This reduces the loss of the tacit knowledge from seasoned veterans leaving the workforce. **Helping employees learn skills and gain knowledge.** Mentoring is an excellent example of informal learning, which is the way people learn 80% of the time in the business world (Schooley et al, 2010). A mentoring program reduces training costs due to the mentor/mentee informal learning relationship, which often deals with content one-on-one that otherwise would be covered in a formal course. It also brings new employees up to speed quickly in those first few months of employment. The chief learning and development officer in a global consulting firm confirms the value of mentoring as a learning tool: "People grow more with human interaction on the job, and we are trying to bring that to all our employees. The best way to learn is from a fellow professional." **Assistance in career growth, building leadership capacity, and increasing bench strength.** Mentees can put their learning on a fast track with mentoring. If they're headed toward management, for example, the mentoring may focus on becoming a better leader and manager. When the mentor shares her own experiences, gives advice, and suggests readings, online courses, or other experiences to help other employees move toward their goals, she builds her own leadership skills in the process. Enhanced bench strength in company leadership ensures successful succession planning and increases productivity.

2.4.2 Performance

The purpose of knowledge transfer is to pass information from the more- experienced to the less-experienced employees so that the less-experienced employees can build the capabilities needed to assume future roles in the organization (DeLong, 2004). Research at both the organizational and individual level of analysis appears to support the notion that knowledge transfer mediates the relationship between mentoring and performance.

As an outcome of mentoring relationships in workplace settings, retention is of interest in this study because of its importance to organizational performance. For decades, management researchers have emphasized the importance of retaining talented employees through research on turnover. If organizations invest in talented employees through increases in their knowledge, the knowledge transferred to these employees is lost if they leave the organization, and the investment made to them. Knowledge workers are increasingly more important for organizational competitiveness today so the knowledge transfer between employees and the retention of key employees is critically important. Organizations with higher levels of mentoring had lower turnover; moreover, they suggested that the mentoring specifically assisted in developing protégés' knowledge and skills. Based on the above research, one may posit that the knowledge and feedback provided to a protégé by a mentor may influence the protégé's turnover intentions.

3. Conclusion

In this paper the authors have endeavored to explain the concept of mentoring by providing an analysis of the term, the types of mentoring and the potential benefits and concerns that have been reported in the mentoring literature. Human resource managers must be aware that mentoring is not an organizational solution. There are concerns regarding the outcomes of mentoring, but it is our opinion that these can be minimized by careful implementation planning. Mentoring is a complex and delicate organizational process and there is little doubt it can be a critical force for organizations, the mentors and the mentees. The results suggest that mentoring is currently rather widely used. The larger the organization the more often it uses mentoring as a formal training. The study reveals the organizations' current situation, and the issues that are important to the HR function. In the context of mentoring these issues are the ageing employees, and the transferrable of tacit knowledge, learning and well-being. Most HR specialist's account that the role of mentoring will change in the future, and the practice will be promoted more than it is currently. This is because as more of the employees retire, the transfer of tacit knowledge becomes more demanding. The simple implication of this paper is that organizations should view mentoring as a potentially beneficial process that requires careful long term planning and skilful human resource leadership. The researcher would recommend to all companies to invest in a coaching and/ or mentoring programme, preferably one that will work for that specific business. Organizations need to research other programs, talk to other executives and find the one that fits the company; the programme needs to be flexible and inclusive when matching the mentor and protégée.

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Implementing BIM for Performing Detailed Construction Estimates in the Classroom

John E. Patterson
Norwich University, Northfield, VT, U.S.A.
jpatter2@norwich.edu

Abstract
Building Information Modeling (BIM) is becoming an integral part of the Architecture, Engineering, and Construction (AEC) industry as a requirement for complete Construction Documents (CD's). As a generation of new practitioners are trained the understanding of BIM is an integral part of the overall educational parameters for CE/CM. The purpose of this study is to present techniques used for assembling detailed construction estimates incorporating BIM. Various estimating process are examined determining the key aspects necessary to develop a detailed estimate. In determining the capabilities of the BIM drawing, the Level of Development (LOD) is presented as a control of the accuracy of the drawings and ultimately the estimate. This study further examines the student's ability to work with BIM modeling. At the conclusion of the course a student survey instrument was provided to the students to examine their skills and confidence.

Keywords
BIM, Estimating, LOD, Schedule, 3D

1. Introduction

As technology advances at an exponential rate, the construction industry is constantly evolving to incorporate technological advances that provide benefit to the end cost (Armstrong & Gilge, 2016). The construction industry has progressed from using rudimentary documents to CAD drawings and word processing and Building Information Modeling (BIM) (AutoDesk, 2018). The introduction of BIM provides a powerful platform to evaluate the entire project through intuitive software. BIM provides the ability to assemble an accurate model of a structure as part of the construction documents (Messner, John, 2017).

The accuracy of the model is dictated by standard BIM protocols published by the American Institute of Architects (AIA) (AIA, 2017). BIM provides, through various computer programs, the ability to create various schedules containing the attributes and numerical quantities pertaining to the structure. These attributes are assembled for developing detailed estimates. The accuracy of the estimate is partially dependent upon the detail of the model. The model allows the students to view as orthographic sheets or a 3-Dimensitonal (3D) rotational representation. These attributes provide the detail for compiling accurate estimates (Messner, John, 2017).

BIM provides a platform to complete conceptual estimates that are provided to the owner as the project develops to keep the owner and designer on budget. Budget analysis allows for making cost decisions on the design to regulate the project's cost and reduce scope creep. The important aspect is that time spent estimating can be reduced allowing for bidding on additional projects, increasing the opportunity for a successful bid. Value engineering is enhanced with BIM, examining the details of the structure for alternative materials and construction procedures (Messner, John, 2017). Design Options are useful for examining differing alternatives both in constructability and cost (AutoDesk, 2018).

2. Class Case Studies

The Construction Management curriculum at Norwich University has two required estimating classes for CM students Specifications and Estimating and Advanced Project Estimating. Prior to taking the estimating courses students' have been introduced to basic construction techniques and *Autodesk* Revit. Revit is the program of choice at Norwich University for creating and maintaining the interrelated data that comprise the database in a BIM (Pluralsight, 2013). Specifications and Estimating is the first of the estimating courses, the course is offered to first semester sophomores. The course covers the obvious, estimating and specifications, but the course content covers the details of reading construction documents, constructability and materials. On-screen viewing of the construction prints in CAD and PDF formats is incorporated in Estimating and Scheduling for presenting the project documents. In the second required course, Advanced Project Estimating, the use of Revit as an estimating, scheduling and electronic estimating tool are incorporated in the course. Revit drawings and accompanying data are exclusively used in Advanced Project Estimating.

The preliminary project examines a simple two car garage (Figure 1). A garage is used for its simplicity and that most students will have an understanding of a similar structure and if not there are similar structures on campus as examples. After completing the initial estimate and have acquired new skills, their attention is directed to a commercial project that has a higher level of difficulty within the project itself and that the students have separate files for architecture, MEP and structural models that are then linked or used independently.

Specifications	
Footings	Roof - Ceiling
12x24	5/12 Roof Slope
No rebar	2x4 Trusses 16" OC
3000 PSI Concrete	5/8" CDX Plywood Sheathing
Foundation Wall	Underlaymennt
12" Block	Shiingles
8" Block Top Brick Ledger Course	Ridge Vent
No rebar	
Block Grout Filled	Finsihes
Horazontal Truss Reinforcement Every Course	Sealant around doors and Windows
Back Fill a Stipulated on Print	Boxing
Slab	Fiber Cement Board (FCB)
3000 PSI Concrete	2 Coats of paint
6x6 10x10 Reinforcement Wire	Boxing Vents - Continuous
Top 4" of Back Fill is Sand	Door Lock
Trowel Finish	Interior Ceiling 1/2" OSB
Wall	
9'-0" Ceiling Height	Electrical
Brick Vineer	Floresent Lights
Brick Wall ties	2 - Exterior Recepticals
1" Air Space	Interior Utiliyt Recepticals
Rolock Window Sills	
House Wrap	
1/2" OSB - Exterior Sheathing	
2x6 Wall Framing	Note:
6" Insulation	The top of these courses of brick are used as
1/2" OSB - Interior Sheathing	form work around the perimeter of the
Single 2x6 Shoe Plate	
Double 2x6 Top Plate	
Window and Door Framing	Note:
Windows	All inspections on this job stop work until
Door	completed and passed
Garage Doors	

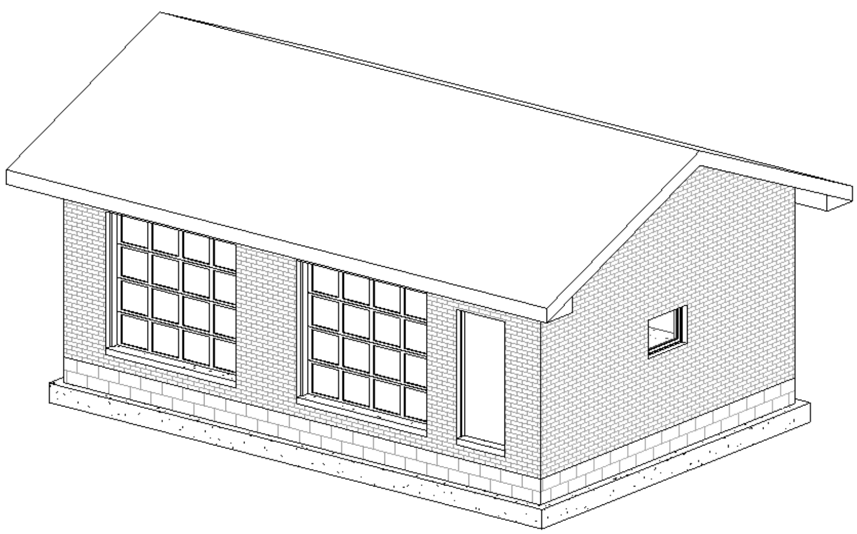
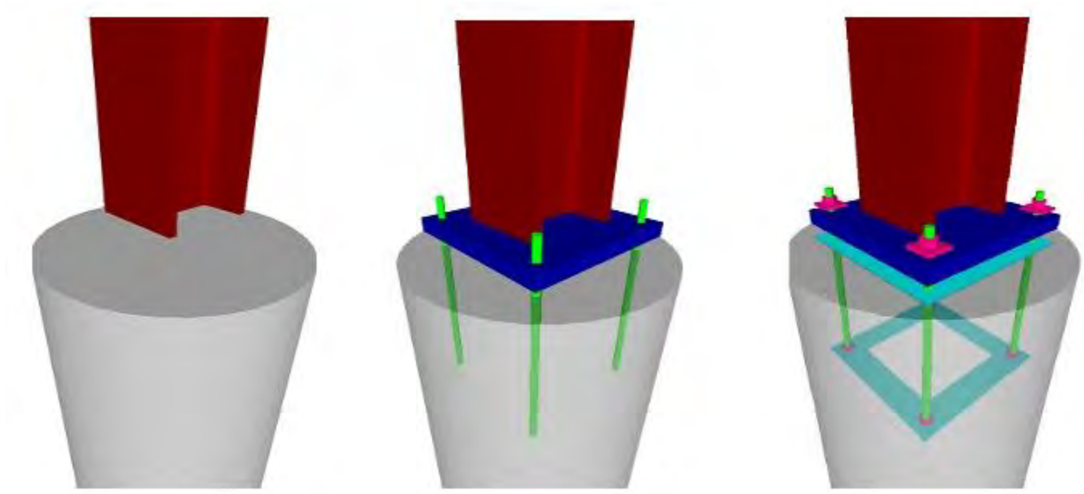


Figure 1: Garage Project

3. Level of Development (LOD)

The first and important step in performing a detailed estimate the structure is to determine the Level of Development (LOD) (Bedrick, 2008). The LOD, published by the BIM Forum, is represented by major contributors to the construction industry (AIA, AGC, and others), to set standards developed to evaluate the BIM for its level of detail. The BIM Forum originally developed an evaluation system enveloped in five basic levels: 100 - Conceptual; 200 - Approximate Geometry; 300 - Precision Geometry; 400 - Fabrication; 500 - As-Build (Bedrick, 2008)

Each LOD has an integral part in possessing data necessary for the completion of the detailed estimate. Level 350, an intermediate level, is used for greater construction detail, and coordination between trades providing order and construction quality (Jizba, 2014). Level 400 provides the greatest detail (Figure 2). A Level 400 development provides extreme detail; shop drawings is an example (BIM-Forum, 2016).



Level 300 Level 350 Level 400

Figure 2: Column Connections – BIM Forum 2016(BIM-Forum, 2016)

When performing a detailed estimate using Revit, a minimum LOD of Level 300 is required for performing a detailed estimate, with a Level 350 or greater is preferred (Bedrick, 2008). The higher the level the greater the amount of data presented in the model. Figure 3 displays a limited selection of the LOD categories that contribute to the accuracy of the estimate and method employed.

UniFormat Levels 100 and 200 provide minimal amount of information that is beneficial for the client to track the developing costs and the feasibility of the project. These projects are being developed during the conceptual phase, modeled using masses. Level 300 is the beginning of the detail necessary for basic estimating. At Level 300 one would be relying on notes and inserted detail clips drawn in CAD. Starting at Level 350 enough detail is provided for a complete estimate, with Level 400 the desired level. The as-built drawing and actual cost is detailed in Level 500 (Bedrick, 2008). The 2015 Element Attributes Tables provides a comprehensive evaluation tool for determining the LOD.

							SD			DD			CD			Estimating			Estimating			LEED Cert,			LEED Cert		
																Est. 1			Bid Pkg.			Check			Submittal		
UniFormat Level				Use on this project			Date			Date			Date			Date			Date			Date			Date		
1	2	3	4			Relevant Attribute Tables	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes
B	20				Exterior Vertical Enclosures																						
B	20	10			Exterior Walls	B – Ext. Wall																					
B	20	10	.10		Exterior Wall Veneer	A, B Masonry																					
B	20	10	.20		Exterior Wall Construction	A, B Cold Formed Metal Framing; A, B Wood																					
B	20	10	.30		Exterior Wall Interior Skin																						
B	20	10	.50		Parapets																						
B	20	10	.60		Equipment Screens																						
B	20	20																									
B	20	20			Exterior Windows	B – Ext. Openings																					
B	20	20	.10		Exterior Operating Windows																						
B	20	20	.20		Exterior Fixed Windows																						
B	20	20	.30		Exterior Window Wall																						
B	20	20	.50		Exterior Special Function Windows																						
B	20	50			Exterior Doors and Grilles	B – Ext. Doors																					
B	20	50	.10		Exterior Entrance Doors																						
B	20	50	.20		Exterior Utility Doors																						
B	20	50	.30		Exterior Oversize Doors																						
B	20	50	.40		Exterior Special Function Doors																						
B	20	50	.60		Exterior Grilles																						
B	20	50	.70		Exterior Gates																						
B	20	50	.90		Exterior Door Supplementary Components																						
B	20	70			Exterior Louvers and Vents	B - Ext. Louvers and Vents																					
B	20	70	.10		Exterior Louvers																						
B	20	70	.50		Exterior Vents																						
B	20	80			Exterior Wall Appurtenances																						
B	20	80	.10		Exterior Fixed Grilles and Screens																						
B	20	80	.30		Exterior Opening Protection Devices																						
B	20	80	.50		Exterior Balcony Walls and Railings																						
B	20	80	.70		Exterior Fabrications																						
B	20	80	.80		Bird Control Devices																						
B	20	90			Exterior Wall Specialties																						

Figure 3: Example of the LOD 2015 Element Attributes Tables 2015-10-30(BIM-Forum, 2016)

4. Problem Statement

As the construction industry embraces BIM, educators need to ensure that they are providing training for students in the use of a Building Information Modeling system. CM curriculums need to examine every opportunity to employ BIM, adding to the body of knowledge presented for the student's training and practice. This study is designed for students to examine the differing methodologies used to assist in producing a detailed estimate. Most students, at this point in their educational career, have a wide range of experience in the basics of BIM through the application of Revit (Pluralsight, 2013). This research examines the effectiveness of Revit as an estimating tool and that using Revit adds to the students' broader knowledge of not only the use of Revit, but that of the constructability of the structure and their estimating skills. As part of this study two separate projects are examined in the class and techniques used. A survey was administered to the Advanced Project Estimating class at the conclusion of the semester. The survey is to measure the student's capacity to use Revit as an estimating tool. The survey instrument, administered to students upon completion of Advance Project Estimating, employs a ten point Likert scale to numerically evaluate the student's responses.

5. Estimating Procedures

This article is presenting methods for performing a detailed estimate based on the a LOD of no less than Level 300, Level 350 is preferred (Bedrick, 2008). The higher the level the greater the amount of data presented in the model. Figure 4 displays a limited selection of the LOD categories that contribute to the accuracy of the estimate and method employed. Uniformat Levels 100 and 200 provide minimal amount of information that is beneficial for the client to track the developing costs and the feasibility of the project. Level 300 is the beginning of the detail necessary for basic estimating. At Level 300 one would be relying on notes and inserted detail clips drawn in CAD. Starting at Level 350 enough detail is provided for a complete estimate, with Level 400 the desired level. The as-built drawing and actual cost is detailed in Level 500 (Bedrick, 2008).

UniFormat Level				Use on this project		Relevant Attribute Tables	SD			DD			CD			Estimating Est. 1			Estimating Bid Pkg.			LEED Cert, Check			LEED Cert Submittal		
							Date			Date			Date			Date			Date			Date			Date		
1	2	3	4				LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes	LOD	MEA	Notes
B	20				**Exterior Vertical Enclosures**																						
B	20	10			**Exterior Walls**	B – Ext. Wall																					
B	20	10	.10		Exterior Wall Veneer	A, B Masonry																					
B	20	10	.20		Exterior Wall Construction	A, B Cold Formed Metal Framing; A, B Wood																					
B	20	10	.30		Exterior Wall Interior Skin																						
B	20	10	.50		Parapets																						
B	20	10	.60		Equipment Screens																						
B	20	20																									
B	20	20			**Exterior Windows**	B – Ext. Openings																					
B	20	20	.10		Exterior Operating Windows																						
B	20	20	.20		Exterior Fixed Windows																						
B	20	20	.30		Exterior Window Wall																						
B	20	20	.50		Exterior Special Function Windows																						
B	20	50			**Exterior Doors and Grilles**	B – Ext. Doors																					
B	20	50	.10		Exterior Entrance Doors																						
B	20	50	.20		Exterior Utility Doors																						
B	20	50	.30		Exterior Oversize Doors																						
B	20	50	.40		Exterior Special Function Doors																						
B	20	50	.60		Exterior Grilles																						
B	20	50	.70		Exterior Gates																						
B	20	50	.90		Exterior Door Supplementary Components																						
B	20	70			**Exterior Louvers and Vents**	B - Ext. Louvers and Vents																					
B	20	70	.10		Exterior Louvers																						
B	20	70	.50		Exterior Vents																						
B	20	80			**Exterior Wall Appurtenances**																						
B	20	80	.10		Exterior Fixed Grilles and Screens																						
B	20	80	.30		Exterior Opening Protection Devices																						
B	20	80	.50		Exterior Balcony Walls and Railings																						
B	20	80	.70		Exterior Fabrications																						
B	20	80	.80		Bird Control Devices																						
B	20	90			**Exterior Wall Specialties**																						

Figure 4 - The LOD 2015 Element Attributes Tables 2015-10-30 (BIM-Forum, 2016)

The student's first project is to perform a detailed takeoff of the Garage Project. The estimate begins by a detailed examination of the construction documents (CD's) this provides the students with an overview of the project. As they examine the prints, check sheets are used as a guide. The check sheets contain accumulated data from previous estimates and the LOD standards.

After becoming conversant with the CD's, the students first main task using Revit as a take-off tool, is to evaluate the prints to determine the LOD of the Revit file. As the model is developed the designers should be following and completing the AIA G202-2013 form to document the Model Development Specification (MDS) (Jizba, 2014). The Element Attributes Tables serve as a tool to verify that the required elements are present in the model. The columns at the far left of the Table define the UniFormat Level or the LOD. After the students determine the LOD Level, the elements of the table can be reordered to reflect the order of construction of the structure, which becomes the outline for their schedule.

With the LOD Element Attributes Tables Check Sheet as a guide the students are able to evaluate the CD's. The change in the headings focuses the students on the elements. Although a Level 100 drawing is not represented in the drawing, but this is used to coordinate the specifications with the drawings. Multiple Uniformat Levels may be indicated, as an example: a simple foundation, the foundation drawing is evaluated to be drawn to Level 350 providing a check in this column and a check in the Level 100 indicating that this is also presented in the specifications. The review will also find those items that are missing and require an RFI for clarification. The drawings may need to revert back to the individual designer for additional clarification and a higher LOD rating. When used as a check sheet, the AIA G202-2013 we incorporate a variation as shown in Figure 5.

UniFormat Level				Use on this project							
1	2	3	4			Relevant Attribute Tables	100	200	300	350	400
B	20				**Exterior Vertical Enclosures**						
B	20	10			**Exterior Walls**	B – Ext. Wall					
B	20	10	.10		Exterior Wall Veneer	A, B Masonry					
B	20	10	.20		Exterior Wall Construction	A, B Cold Formed Metal Framing; A, B					
B	20	10	.30		Exterior Wall Interior Skin						
B	20	10	.50		Parapets						
B	20	10	.60		Equipment Screens						
B	20	20									
B	20	20			**Exterior Windows**	B – Ext. Openings					
B	20	20	.10		Exterior Operating Windows						
B	20	20	.20		Exterior Fixed Windows						
B	20	20	.30		Exterior Window Wall						
B	20	20	.50		Exterior Special Function Windows						
B	20	50			**Exterior Doors and Grilles**	B – Ext. Doors					
B	20	50	.10		Exterior Entrance Doors						
B	20	50	.20		Exterior Utility Doors						
B	20	50	.30		Exterior Oversize Doors						
B	20	50	.40		Exterior Special Function Doors						
B	20	50	.60		Exterior Grilles						
B	20	50	.70		Exterior Gates						
B	20	50	.90		Exterior Door Supplementary Components						
B	20	70			**Exterior Louvers and Vents**	B - Ext. Louvers and Vents					
B	20	70	.10		Exterior Louvers						
B	20	70	.50		Exterior Vents						
B	20	80			**Exterior Wall Appurtenances**						
B	20	80	.10		Exterior Fixed Grilles and Screens						
B	20	80	.30		Exterior Opening Protection Devices						
B	20	80	.50		Exterior Balcony Walls and Railings						
B	20	80	.70		Exterior Fabrications						
B	20	80	.80		Bird Control Devices						
B	20	90			**Exterior Wall Specialties**						

Figure 5: LOD Element Attributes Tables Check Sheet

With the evaluation phase of the estimate completed the students advance to the second phase, that of extracting data to perform an estimate. The LOD indicates the extent and level of detail available from Revit. Data is presented through a series of schedules, a tablature assembly of data containing the materials and quantities contained in the model. Revit has several categories of schedules that program will assemble. There are six levels of schedules available for different functions. The two main Schedule choices for estimating are Schedule/Quantities and Material Takeoff. The only information that is available for display in a schedule is that that is contained within the designer's database. If additional data is needed, such as the ceiling height, because it is not a provided Field, a column is added that contains a formula that divides the area of the wall by the length to derive the wall height, similar to creating Excel formulas.

<Wall Schedule>									
A	B	C	D	E	F	G	H	I	J
Line Number	Family	Type	Area	Length	Width	Unconnected Height	Wall Area	Actual Wall Length	Actual Wall Area
Exterior - Brick and CMU on MTL. Stud									
1	Basic Wall	Exterior - Brick and CMU on MTL. Stud	240 SF	28.84	1.16	8' - 0"	230.75	30' - 0"	240 SF
2	Basic Wall	Exterior - Brick and CMU on MTL. Stud	151 SF	18.84	1.16	8' - 0"	150.75	20' - 0"	160 SF
3	Basic Wall	Exterior - Brick and CMU on MTL. Stud	151 SF	18.84	1.16	8' - 0"	150.75	20' - 0"	160 SF
4	Basic Wall	Exterior - Brick and CMU on MTL. Stud	201 SF	28.84	1.16	8' - 0"	230.75	30' - 0"	240 SF
Exterior - Brick and CMU on MTL. Stud: 4			742 SF	95.38			763		800 SF
Grand total: 4			742 SF	95.38			763		800 SF

Figure 6: Wall Schedule with Formulas

A Multi-Category schedule will produce a document with all the modeled components of the structure (Figure 6). This schedule can be very long. The advantage in this type of schedule is that it provides all the components that can be modeled and separate schedules may be necessary to have the detailed information needed. Have the students evaluate their schedule options with different types of schedules and the fields that you may add. The key to successfully compiling an estimate is dependent on the assembly of the Schedule using the provided data and the estimator's ability to create formulas.

The first step in extracting data from Revit is to create the schedule. Choosing the proper schedule and attributes ensures that the data presented in the schedule is proper and accurate. Creation of schedules can be a simple or complex depending on the manner in which the drawing was prepared. Another consideration in developing a schedule is the ease of transferring data to WinEst. The required units can dictate whether the dimensions need to be presented in feet and inches or a decimal equivalent. The metric system (not used as a standard in the U.S.A.) would circumvent this dilemma.

Previously a simple Wall Schedule was examined (Figure 6). In the schedule the units were changed for the wall length segments from feet and inches to the decimal equivalent. Students select the column then select Format Unit (Figure 7).

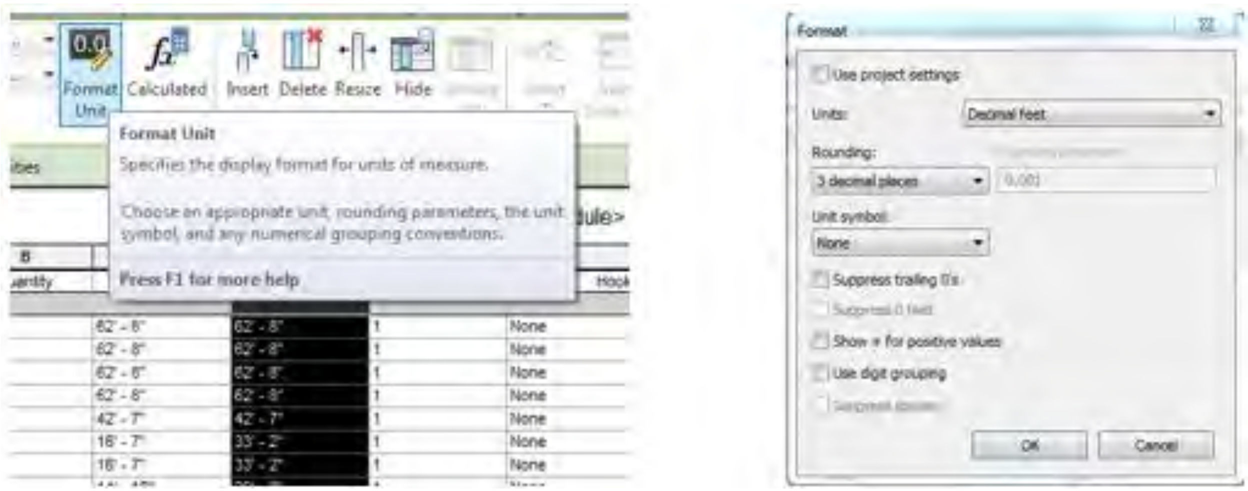


Figure 7: Conversion of Units

Change the units to Decimal feet. To make the Units selection visible you will need to delete the check mark from the Use project settings. By converting to Decimal feet this allows for adding the quantities once the data is exported to an Excel Spreadsheet. The maximum allowable rounding is to 3 decimal places. Selecting Rounding to 3 decimal places to provide a higher level of accuracy to the conversion.

Once the schedule is created and the Units adjusted sorting of the data before exporting is advantageous for clarity. To sort the data in the Properties dialog box, select Sort/Grouping. The Schedule Properties dialog box is now open sort first by Type and check the box for a Blank Line to be added. This places a blank line between the different types of rebar. The students then will export their data to a *Microsoft* Excel spreadsheet and/or manually enter the data in WinEst to complete their estimate

6. Results

At the conclusion of the semester long test course, a survey was completed by the students examining their knowledge of BIM, comparing their skill level at the beginning of the semester to that at the end of the semester, and if Revit assisted in compiling their estimates. The five questions below were part of the completed survey. Each of the questions were evaluated by the use of a ten point Likert scale. The questions and statistical analysis of the student's responses is presented in Table 1.

Table 1: Survey Questions and Survey Statistical Results

No.	Survey Question	Mean	Median	Mode

1	At the beginning of the spring 2017 semester how would you rate your proficiency with using Revit?	2.57	2	0
2	At the end of the spring 2017 semester how would you rate your proficiency with Revit.	6.48	6	6
3	Compared to manual estimating methods used in Estimating I, did using Revit improve your estimate, verses using AutoCAD prints?	7.30	7	7
4	Traditionally estimators are supplied with orthographic prints and specifications to complete their estimate. Revit drawings offer Building Information Modeling (BIM) 3D imaging, orthographic views and the database associated with the structure. Did the Revit files and aid in compiling your estimate?	7.52	8	7
5	How well did Revit drawings and accompanying data add to your understanding of the project, verses traditional orthographic drawings.	8.09	8	9

7. Discussion

When examining the student's responses interesting results are presented. The student's prior knowledge of Revit, before attending the class, is very limited as indicated in Question 1. With an average response of 2.57, and a mode of zero, the students had a low understanding of Revit at the beginning of the semester. In contrast Question 2 is examining the student's capabilities at the end of the semester of using Revit as an estimating tool, indicating a substantial increase in their understanding of Revit at an average of 6.48. In comparison to the first question the students increase of knowledge of using Revit has increased 2.52 times when comparing the means.

Questions 3, 4 and 5 examine the application of Revit as an estimating tool in comparison to previous estimating experiences in the Specifications and Estimating class. In each instance the students provided favorable responses of, 7.50, 7.52 and 8.09, respective to the questions number. In Specifications and Estimating the students use orthographic drawings provided electronically in AutoCAD or PDF format. Using Revit, a program that that they had a low understanding of at the beginning of the semester, has drastically increased the student's ability to use Revit as a BIM tool, it has similarly improved their understanding of the project and their estimates.

8. Conclusions

The results of this research has validated that the techniques used in Advanced Project Estimating employing BIM (Revit) as an estimating tool, not only has their Revit skills improved, but the accuracy of their estimates has improved. BIM provides the opportunity for students to examine the project in 3D or in orthographic style assists students to visualize the project thus a better understanding of the project's requirements. The inclusion of BIM in an estimating program has numerous benefits beyond as an estimating tool. The estimate will follow this structures beyond the completion of the project when as-built documents are compiled. The information contained in a BIM provides students with the necessary data for completion of a detailed estimate, aided the students with their understanding of the project and processes required to construct the structure.

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Alternative Housing Solutions in Southern California

Scott Kelting
(Associate Professor, California Polytechnic State University, San Luis Obispo, California, USA)

Lucas Nozick
(Project Engineer, WEST Builders, Culver City, California, USA)

Abstract
The perpetually growing population and economy within the United States necessitates building construction of all types. Increased building generates environmental concerns, and rightfully so. This industry accounts for approximately 4% of the total GDP in the United States, while creating around two-thirds of the material waste annually. The green building movement is certainly gaining popularity in both application and recognition through entities such as the United States Green Building Council (USGBC) and their LEED program; however builders are also producing their own ideas. Alternative housing solutions that include pre-fabricated building components and shipping container homes are making great strides in the residential construction industry, and will certainly play an important role in the future. This paper will compare the cost and schedule of modular, panelized and shipping container homes to traditional stick frame home construction in the Greater Los Angeles Metropolitan Area and recommend the best application for each option.

Keywords
Stick Framed, Prefabricated, Shipping Container, Cost, Schedule

1. Introduction

As environmental concerns grow, so does the alternative housing industry. Customers are looking for quality end products built both efficiently and durably at the cheapest cost to them. Traditional stick frame homes have been, and will continue to be, the industry standard. In 1975, the average home in the U.S. was around 1600 square feet and housed 3.11 people. Today, the average home has increased to 2300 square feet and houses just 2.58 people. Not only has the average occupant size decreased, but square footage has increased 44%. This increase in home size demands more raw resources for construction, thereby creating more construction waste. In an industry where approximately one billion board feet of salvageable lumber (or approximately 62,500 homes worth) is thrown out each year nation-wide, this change is concerning (Barrows, 2013). This concern has inspired a new housing movement aimed at reducing construction waste, recycling previously used materials, and increasing quality of homes.

General contracting firms traditionally focus on the markets that their clientele are most willing to spend their money. Niche markets, such as sustainable building, are often overlooked in favor of the status quo. Recently, however, the alternative housing movement has shown great promise. Utilizing a number of innovative construction methods, specialized firms are able to reduce overall project costs and schedule, while also delivering quality end products. Focusing on prefabricated and recycled shipping container homes, these firms are paving the way for the sustainable building movement.

2. Background

Before analyzing the cost and schedule used in alternative housing, it is important to discuss and understand the solutions available today. Customers can select the prefabricated route, through either modular or panelized homes, or they may opt to build with recycled shipping containers. All three options have their strengths and weaknesses relative to one another and to traditional stick framed home construction.

2.1 Stick-Framed Homes

Traditional stick framed homes account for over 90% of all new homes built in the United States each year (Wardell, 2016). As the go-to method of construction, most residential general contracting firms are well versed in stick-built home construction. Stick-built refers to homes that are constructed using wall studs, floor and ceiling joists, and roof trusses or rafters (Wardell, 2016). A crew in the field must size each wood element individually before nailing it all together. This is a time consuming process that results in a great deal of inefficiencies including wood waste. Further, a stick-built home must be constructed on site, and is therefore susceptible to poor weather conditions and potential theft. According to reports conducted by the Department of Wood Science and Forest Products at Virginia Tech and the USDA Forest Service Southern Research Station, the construction of an average 2,000 square foot home results in 1,500 to 3,700 pounds of solid wood waste and 1,000 to 1,800 pounds of engineered wood waste (Barrows, 2013). What can builders do to reduce this waste? One option is to recycle the cardboard, wood and drywall – which account for 60 to 80% of the total waste on a job site – and re-use these materials elsewhere (Barrows, 2013). Another way to reduce this waste is to construct homes using prefabricated building methods.

2.1.1 Modular Homes

Modular homes are an increasingly popular form of prefabricated construction. These homes are constructed by connecting separate pre-fabricated box-like modules that have been individually constructed in factory conditions and transported to the job site to create a home (JElitzer, 2016). Because they are constructed in optimal, protected conditions, many delays and waste resulting from bad weather in the field are eliminated at the source. Factory operations are set up to minimize waste and maximize profit, so the laborers performing the work are highly specialized in constructing the similar modules time and time again. All modular components adhere to state and federal building codes, so they are at least as safe as their stick-built counterparts (JElitzer, 2016). Modular homes, especially with modern innovations, offer clients a great deal of customization; however, stick-built homes generally offer more. One issue surrounding modular homes is perceived value; home buyers often feel that modular homes are cheap and lack the quality associated with traditionally built homes (Gassett, 2015). Data says otherwise, however, as modular homes are considered to be of equal quality, if not better.

2.1.2 Panel-Built Homes

Panel-built homes are also constructed using prefabrication techniques. Panelized wall systems form the structural envelope of a home, eliminating the need for on-site conventional wood framing. Panelized wall systems only account for 8% of the residential construction market, yet they offer many advantages to builders including a shorter installation time that requires less skilled workers (Wardell, 2016). Similar to modular homes, panels are prefabricated in factory conditions, improving quality and reducing construction waste. Although factory-built panels may cost more than stick-framed building techniques, the installation time is greatly reduced, resulting in potential net-positive cost savings, based on the availability of labor. Panelized walls provide occupants with better overall air tightness and thermal performance, resulting in a more comfortable living environment in both hot and cold conditions (Wardell, 2016). Panelized homes also offer a great deal of customization, and designers and engineers can send their plans directly to the factory for dimensionally accurate panels (Lingerfelt, 2016).

2.1.3 Shipping Container Homes

Today, an abundance of decommissioned shipping containers are sitting idle in locations all over the United States. A typical shipping container is around 20ft by 8ft, and provides 160 square feet of usable space. When stacked side by side and on top of one another, these shipping containers can provide a nicely-sized living environment. Also referred to as intermodal steel building units (ISBU), shipping containers are durable and cheap, often costing as little as $2000 each. Shipping containers are built to withstand water, wind, rust, mold, fire and pests, making them an exceptional building shell (Martinez-Garcia, 2014). Shipping containers can be fitted with all of the amenities of a traditionally built home, including bedrooms, bathrooms, kitchens and common areas. Windows and doors can be cut into the shell of the container, providing natural lighting to the occupants. Shipping container homes are easily transported, and offer a sustainable living solution.

3. Methodology

The researcher intends:

- To analyze the costs and schedule of modular, panelized and shipping container home construction
- To compare the data collected for the alternative housing solutions to comparable stick-framed home construction
- To discuss the pros and cons of each housing option
- To offer recommendations as to the best application for each solution

The data used in this paper will be primarily quantitative. Raw factual numbers are the best means to compare cost and schedule. However, certain qualitative date will also be analyzed in weighing the pros and cons of each solution relative to quality of life such as comfort and aesthetics. Both qualitative and quantitative data will be considered in offering recommendations for alternative housing applications.

4. Results

4.1 Cost

For a majority of homebuyers, cost is the most important factor when considering their housing options. Building methods, quality of materials and craftsmanship, location of construction, transportation costs and operating costs all influence the final price of the project, both during the building process and over the life of the home. Each alternative housing solution carries costs in different ways, so it’s important to understand these factors. The most simplistic statistic to compare regarding cost is the average price per square foot.

Table 2. SINGLE-FAMILY HOMES SALES PRICE BREAKDOWN HISTORY

Sale Price Breakdown	1998	2002	2004	2007	2009	2011	2013	2015
1. Finished Lot Cost	23.6%	23.5%	26.0%	24.5%	20.3%	21.7%	18.6%	18.2%
2. Total Construction Cost	54.8%	50.8%	51.7%	48.1%	58.9%	59.3%	61.7%	61.8%
3. Financing Cost	1.9%	2.1%	1.8%	2.4%	1.7%	2.1%	1.4%	1.3%
4. Overhead and General Expenses	5.7%	5.5%	5.8%	7.0%	5.4%	5.2%	4.3%	5.6%
5. Marketing Cost	1.4%	2.4%	1.9%	2.5%	1.4%	1.5%	1.1%	0.8%
6. Sales Commission	3.4%	3.7%	3.0%	4.3%	3.4%	3.3%	3.6%	3.2%
7. Profit	9.2%	12.0%	9.8%	11.2%	8.9%	6.8%	9.3%	9.0%
8. Total Sales Price ($)	$226,680	$298,412	$373,349	$454,906	$377,624	$310,619	$399,532	$468,318

Source: NAHB Construction Cost Surveys, 1998-2013

Figure 1: Single-Family Homes Sales Price Breakdown History

How is the cost of a traditional home broken down? The chart above demonstrates the sale price breakdown of a home. This cost breakdown is a national average and will vary by region; however, it gives a good estimate as to how costs are carried in a home. Unsurprisingly, the cost of construction itself represents a large proportion of the total price. The finished lot also represents approximately 20% of the total price; however, this is more substantial in Los Angeles as land is significantly more expensive than in most other locations. According to the graph below, the average price per square foot of a stick-built home in the Los Angeles area is around $575, including the final lot price (Value). If lot price were to be excluded, the average is around $460, if lot is considered to be 20% of the final home price.

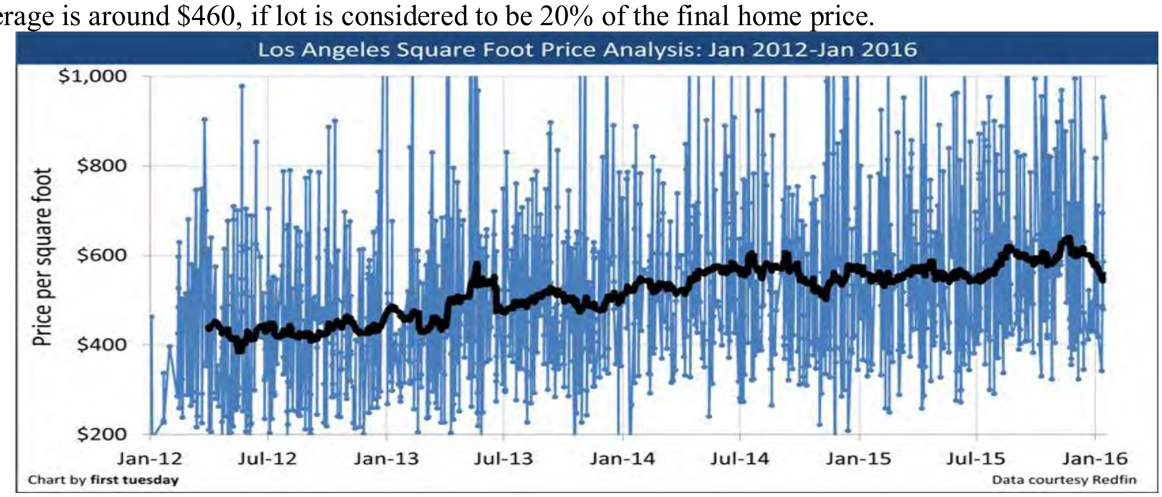

Figure 2: Los Angeles Square Foot Price Analysis

One major concern regarding modular, panelized and shipping container homes is access to lot. A customer interested in purchasing one of these homes will need land in which to place their dwelling. More than likely, this lot will need to be cleared and grubbed, graded and finished before it can accept a foundation. Alternative housing companies in the Los Angeles area often price their homes for the material and construction costs associated with the building itself, with foundation and site work as extras. These costs can certainly add up. For the purpose of this comparison, the price of a lot will be excluded.

What can a homebuyer expect a modular home to cost? LivingHomes, which provides modular home construction services in the Los Angeles area, quotes a price range of $139-$230+ per square foot, with additional need-based costs of $70-$90+ per square foot for customization, permit fees, engineering, transport, install, and foundation or site construction administration fees on a flat lot. Adding these two together, the price ranges between $209 and $320+. Of this range, the transport/install costs average around $25/square foot. Their homes are equipped with all the amenities of a higher end traditional stick-built home, with the added bonus of at least a LEED-silver level of materials and energy systems. When compared to their traditional stick-framed home counterparts, these modular homes are about around 30% cheaper at the high end while providing similar, if not better, value.

Similar to modular, panelized homes cost less per square foot than traditional stick-framed homes. Proto Homes, also located in Los Angeles, offers customers options ranging from a $175/square foot bare-bone building envelope ready for customization to a $275/square foot fully-finished product. Proto Homes also quotes costs from $50,000 to $100,000+ for site prep, permitting, consulting, contractor work and utility service installation costs. An approximately 2,000 square foot home ranges from $200/square foot to $325/square foot depending on existing lot conditions of the client. Again, this is 30% cheaper than a traditional stick framed home at the high end.

The costs associated with shipping container homes vary greatly. A customer may choose to purchase an unmodified shipping container or an already finished product from a specialized builder. A reputable firm will adhere to code and permitting requirements and provide a safe and comfortable end product. If a client decides to build it themselves, they can purchase decommissioned shipping containers through the Port of Long Beach. Companies, such as RailBox Consulting, offer 8'x20' shipping containers for around $1500, and 8'x40' shipping containers for around $1700. Shipping the container to a lot costs from $325-$675 depending on the size and location of the site. MEKA Homes offers a variety of finished shipping container homes shipped directly to the customer. Their homes don't require special skills to install on a finished lot. Products are available ranging from $193 to $267/square foot, with additional costs of foundation, roof finishes, and on-site assembly varying by region. These prices also don't include kitchen appliances. Still, these functional, finished homes are over 40% cheaper than traditional stick framed homes at the high end.

4.1.1 Schedule

Another advantage that alternative housing solutions offer is a reduced construction schedule. What can a customer expect a typical project schedule to look like for traditional stick-framed homes and each of the alternative housing solutions?

The construction schedule applied to stick-framed home varies greatly. The schedule for any given project is generally measured in terms of months; permitting, location, size, skill of contractor, quality of finishes, and many other factors affect the overall duration. According to the United States Census Bureau, owner-built homes in the Western United States take an average of .5 months after obtaining proper permits to begin construction, and a further 12 months on average to finish. In a large city such as Los Angeles, this average is extremely optimistic as jobsite accessibility is often greatly reduced and skilled labor can be difficult to find. Being out of a permanent living situation for a year or more puts a great deal of pressure on a new homeowner and leaves them vulnerable to market fluctuations in material and labor prices. Further, the longer the home takes to build, the more exposed crucial elements of the structure are to adverse weather conditions and theft.

Prefabricated modular and panelized homes allow for a greatly reduced overall project schedule as a result of streamlined building processes and on-site installation.

Modular homes can certainly be built more quickly than traditional stick-framed homes. The factory that constructs the individual modules will have all necessary materials already on-site, greatly reducing material importing time from their respective sources. Weather conditions such as rain, snow and strong winds result in major schedule delays when construction occurs on site. Modular home components are primarily built inside a factory in optimum conditions and protected from any poor weather outside, effectively negating these delays (Gassett, 2015). Further, the module production in the factory and all of the site preparation and foundation work may occur simultaneously. This simply isn't possible in traditional stick-framed home construction which requires the foundation to be completely finished before framing can begin. The chart below represents a typical modular home construction schedule by Living Homes. Their standard option reduces the overall construction duration by approximately 6 weeks when compared to a comparable stick-framed home. Custom, complicated stick-framed homes can take 18 months or more to complete; Living Homes offers similar options that take nearly 6 months less.

The construction schedule of panelized homes also benefits greatly from the utilization of factory-built components. Like modular homes, delays due to weather, on-site material deliveries and subcontractor schedules are significantly reduced or eliminated entirely (Lingerfelt). Proto Homes also offers completed homes in under a year. The chart below shows a typical panelized home schedule, which can range from 9 to 12 months.

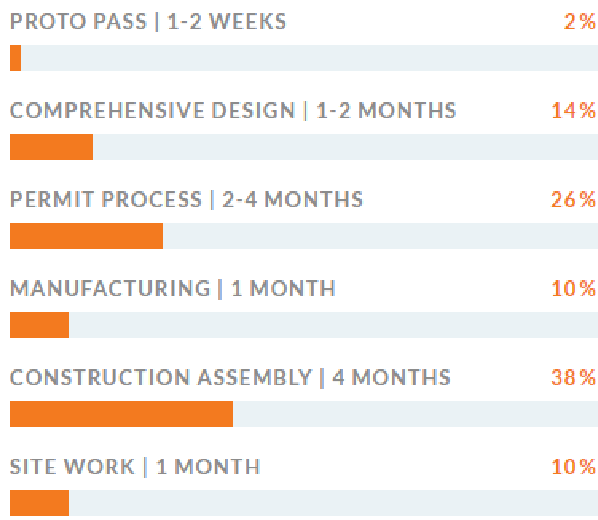

Figure 3: Proto Homes Construction Schedule

The most notable feature of the schedule is that the site work, manufacturing and construction assembly process takes approximately 6 months. This process takes 12 months on average in a traditional stick-framed home.

Shipping container homes have the shortest construction schedule of all four options. The amount of time required to transport, build and install a shipping container home for an individual purchasing decommissioned containers directly from the source is entirely dependent on their skill and experience. However, if a homeowner decides to purchase a finished product through a reputable company such as MEKA Modular, a one-bedroom/bathroom 480 square foot home can be installed and move-in ready in just a week (Martinez-Garcia, 2014). Add an additional one to two months for the actual retrofitting and finishing of the container, and you're looking at an under three month total construction schedule. Shipping containers have been used in disaster relief and outpost applications for both military and government entities. Both demand exceedingly quick mobilization to help those displaced and during wartime operations. Pre-fitted shipping containers in both residential and governmental applications simply need to be transported to their destination site and secured to a pre-existing foundation (Martinez-Garcia, 2014).

Conclusions and Recommendations

The increasing demand for housing is stimulating innovation and creativity across the construction industry. In a population hub such as Los Angeles, this is especially true. Traditional stick-framed homes, while the most palatable and popular option, no longer provide the most cost-effective and schedule-friendly products to homebuyers. Alternative housing solutions that utilize prefabrication methods and decommissioned shipping containers offer many advantages to those in the market for a new home. However, each solution has its pros and cons and applications in which they are best applied.

Prefabricated homes are often cheaper and can be constructed more quickly than traditional stick-framed homes. They offer comparable or superior quality both structurally and aesthetically. Many of the components in both modular and panelized homes are constructed by experienced laborers in a factory and require minimal skill to assemble once on a jobsite. This is beneficial if skilled subcontractor labor is hard to find as the quality of a stick-framed home will diminish under such conditions. The entire construction process is also less susceptible to adverse weather conditions; however, Los Angeles generally has great weather year-round. The main concern with pre-fabricated homes is transportation. Each component must be individually shipped to its site. Depending on the area, this can be quite difficult in Los Angeles when considering traffic and accessibility conditions. Still, shipping individual pre-made modules requires fewer trucks than would needed to transport each unique component of a house. Perceived value is also an issue a homeowner faces when purchasing a prefabricated home; reselling will be more difficult. As prefabricated homes increase in popularity, as they already are, this perception will certainly change.

Shipping container homes also suffer from transportation concerns. Most containers up to 40’ long and 8’ wide can be shipped on a flatbed truck in one lane on a highway. Depending on the final lot location, it may be difficult for a truck of this size to deliver the shipping containers to their final destination. Crane access is also difficult, making it complicated to stack the containers once on site. If site accessibility isn’t an issue, a shipping container home is a fantastic option, providing an extremely durable and comfortable living space. A shipping container home will also stand up well in the seismically active Los Angeles area. If the owner likes to move frequently, the shipping container home can be transported to their new destination with relative ease.

Los Angeles is a great market in which to take full advantage of alternative housing solutions. Ultimately, it’s the decision of the homebuyer based on their needs and monetary situation. Most prefabricated and shipping container specialty builders offer feasibility surveys in order to determine if their solution is practical. Homebuyers should take full advantage of these services in making their selection. One thing is certain; homebuyers have more options than ever before.

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SCIENTOMETRIC ANALYSIS OF BUILDING INFORMATION MODELLING (BIM) IN FACILITY MANAGEMENT (FM)

Mustafa A. Hilal[a,b]
[a] *Faculty of Engineering and Idustrial Science, Swinburne University of Technology, Melbourne, Victoria, Australia*
[b] *Faculty of Civil Engineering,University of Baghdad, Baghdad, Iraq*
mhilal@swin.edu.au

Tayyab Maqsood[c]
[c] *School of Property, Construction and Project Management,RMIT University, Melbourne, Victoria, Australia*
tayyab.maqsood@rmit.edu.au

Amir, A.[d]
aabdekhodaee@swin.edu.au
[d] *School of Engineering, Department of Mechanical Engineering and Product Design Engineering, Swinburne University of Technology, Melbourne, Victoria, Australia*

Abstract
Over the last few years, the emergence of BIM has successfully achieved a paradigm-shift in Architectural-Engineering-Construction and Facility Management (AEC/FM) sectors. This has led to many articles and papers that have been published in those sectors. In order to statistically classify and categorize those publications, Bibliometric and Scientometric Analysis research have been conducted to extract much useful information. However, the existing research sheds a light on the use of BIM in the construction industry in general, focusing on the design and construction phases. Literature review has shown no Bibliometric and Scientometric Analysis of BIM in FM in particular. This research addresses this lack and establishes the first Scientometric Analysis study of BIM in FM. This study employed a quantitative approach using science mapping techniques to examine BIM-FM articles using the Web of Science (WOS) database for the period between (Jun 2003- Oct 2017). The findings guide researchers who are interested in BIM-FM topics by providing visual maps analysis of that area in a simple, easy, and readable way. Finally, knowledge gaps in this domain can be identified more easily with those findings of Scientometric Analysis.

Key Words: Scientometric Analysis, FM, BIM, Construction Industry, Web of Science.

1. Introduction

Building Information Modelling (BIM), which is also known as Virtual Prototyping Technology, has rapidly changed the world of the construction industry. According to Azhar et al. (2012), BIM is both a process and a technology. The technology component helps project members to visualize the construction activities of the whole project in a simulated environment to recognize any potential design, construction, and operational conflict while the process part enables a high level of cooperation and promotes the integration of the functions among stakeholders on the construction projects. Despite this growing interest in AECO by implementing BIM, however, analysis on the status of BIM is scarce, specifically in the FM sector. Researchers have yet to statistcally analyze the quality and amount of research that has been achieved in this field in a comprehensive way. This limitation has led to the need for the current research. A Scientometric Analysis has been used in this study using the WOS database to find the research fields with the highest research output, the countries in charge of most BIM-FM research, the journals that publish most research, top citations, and the most famous authors.

2. FM Concept

Until now, there has been no clear and specific definition for FM. That is why there are many definitions that define FM from different perspectives. The International Facility Management Association (IFMA) defined FM as " A Profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology (IFMA, 2014). Facility Management has Also been described as "a hybrid management discipline that combines people, property and process management expertise to provide vital services in support of the organization"(Shiem-Shin Then, 1999).
Further, Schneider et al. (2006) defined FM as “operating a group of assets over the whole technical lifecycle guaranteeing a suitable return and ensuring defined service and security standards”. Atkin and Brooks (2009) cited Barrett and Baldry (2003), who defined facilities management as “An integrated approach to maintaining, improving and adapting the buildings of an organization in order to create an environment that strongly supports the primary objectives of that organization."
According to Ikediashi (2014), most of these definitions relate to the fact that FM is about integrating process, people and place as illustrated in Figure (1):

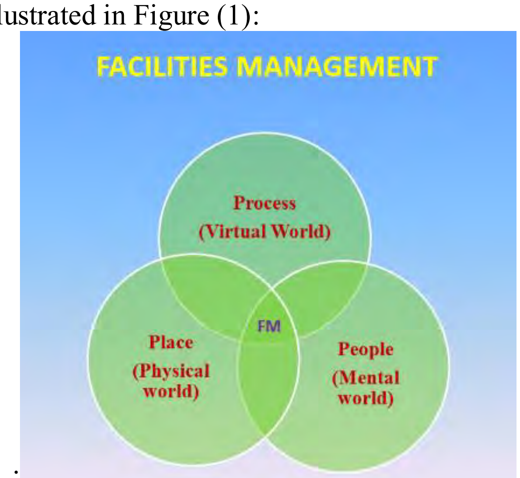
:

Figure (1) Facility Management components (Ikediashi, 2014)

In fact, the operation and maintenance phase in building projects is considered the longest phase of the building lifecycle. It shares about 60-85% of the total life-cycle cost, whereas both the design and construction phases account for 5-10% (Lewis et al., 2010). In the same context, according to (Teicholz, 2004), less than 15% of the total cost of ownership is spent on design and construction while the remaining percent spent on the operation and maintenance phase. Consequently, many researchers have recommended optimizing this sector by adopting more advanced processes and technologies. The following sector discusess BIM adoption and its potential benefits to all project phases including the FM.

3. Building Information Modelling Definitions

There are many definitions of BIM-based on different perspectives. For example, the National Building Information Modelling Standards (NBIMS) committee of USA defines BIM as; “a digital representation of physical and functional characteristics of a facility (NBIMS, 2007). Further, Succar (2010) defined BIM as "a set of interacting policies, processes, and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building's life-cycle".

4. Research methods for the current study

Science Mapping represents how fields, specialties, disciplines, and individual authors or documents are correlated to one another (Small, 1999). It has proven benefits in dealing with comprehensive bodies of literature visually and statistically. According to Cobo et al. (2011), Science Mapping has certain features in depicting systematic patterns in a massive amount of literature and bibliographical units.
Scientometric Analysis, Bibliometric Analysis, and Informatics Analysis can be categorized under Science mapping studies. Scientometric analysis has been adopted in this study due to its comprehensive capabilities and freely available software such as VOSviewer. Zhao (2017) in his study *“A scientometric review of global BIM research: Analysis and visualization”* employed a scientometric method for analysing global BIM research between 2005 and 2016. He conducted co-citation analysis, co-author analysis, and co-word analysis. A Total of 614 dataset records from the Web of Science database was analyzed. This study captured related BIM literature in the construction industry in general. Following are some of his scientometric analysis findings in term of a co-word network and a journal co-citation network illustrated in Figure (2).

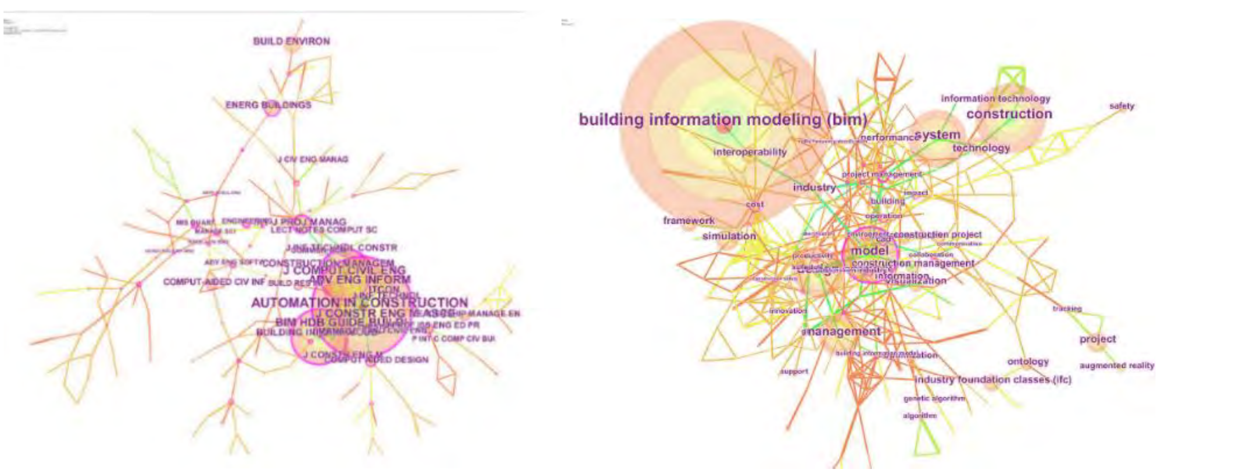


Figure (2); source (Zhao, 2017)

In the same aspect, He et al. (2017) study “Mapping the managerial areas of Building Information Modelling (BIM) using scientometric analysis” dealt with similar aspects.
They employed abstract and keyword term analysis of 126 related articles published between 2007 and 2015. Their findings showed the transformation of BIM from an individual approach to a wide-ranging organizational strategy. The study provided a new way of managing BIM projects by providing an accurate representation and analysis of previous efforts.

Previous literature has argued the importance of BIM in the whole project lifecycle. However, none of them studied BIM in FM in particular. Accordingly, this study aims to bridge this gap. It considered the first Scientometric analysis for BIM in FM. Science mapping has been adopted as the main methodology due to its descriptive and diagnostic merits.

1. Selection of tools

Scientometric analysis has different available tools such as VOSviewer, BibExcel, CiteSpace, CoPalRed, Sci2, VantagePoint and Gephi (Cobo et al., 2011). VOSviewer was used in this study, as it is simple, freely available and has a wide range of features to achieve the Scientometric networks effectively.

2. Data acquisition

VOSviewer allows users to download bibliographic records directly from the Web of Science (WOS), Scopus, Google Scholar and PubMed. From these options, WOS was selected for its reliable searching features and the availability of most sources. The search keywords in WOS was “Facility Management” OR “Facilities Management” OR “Asset Management” OR “Assets Management”, to retrieve the bibliometric data associated with published studies on FM in general. The search had timeframe limitation with the date range set between 2003 and 2017. Searching attempts using these keywords were conducted on the title of published studies only. This produced more than 1300 documents. After that, the results were refined based on limiting the search by applying another keyword, specifically “BIM”, to filter only articles published in the area of BIM-FM which is the objective of this study. On 1st Oct 2017, 41 articles were identified, for which all bibliometric data were extracted and downloaded from WOS, forming the database used in this study.

3. Scientometric techniques

A scientometric analysis was adopted for this study in two stages. The first stage included the creation of networks through analyzing the co-occurrence of keywords, and co-citation analysis (references, sources, authors), and co-authorship analysis (author, organization, countries). In the second stage, the generated maps in stage one were analyzed to distill useful information. Price and Gürsey (1975) stated that these measures showed “the conceptual, intellectual, or social evolution of the research field, discovering patterns, trends, seasonality, and outliers”.

5. Findings and Discussions

The following sections present the research findings. It is worth mentioning that VOSviewer Software shows all *letters* in **lowercase** and this can be a bit confusing for readers, as they are not used to deal with this status. For instance, BIM will be shown as *bim,* and so on.

1. Timeline trends of BIM-FM research

As mentioned, the search criteria have been set to include any year between 2003- Oct. and 2017. Figure (3) shows the number of publications in each year. For instance, in the year 2015, the number of publications is the highest with 12. In general, the figures show an increase in the number of publication in BIM-FM during the time with a minor fluctuation in the last two years. No, research between was between 2003 and 2009.

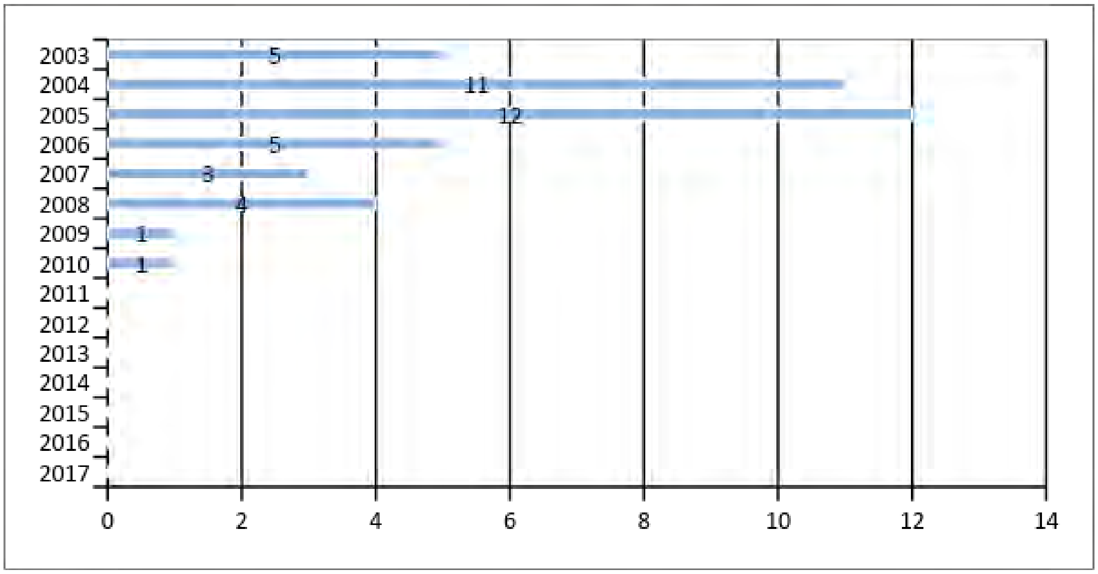


Figure (3) Publication year

It is worth noting that the first study on BIM-FM within the dataset was entitled 'Active3D: Semantic and Multimedia Merging for Facility Management' by Vanlande, Renaud; Cruz, Christophe and Nicolle, Christophe (2010), published in the 6th International Conference on Web Information Systems and Technologies in Valencia, SPAIN on 2010. The poverty of research in the BIM-FM area can be seen clearly.

2. Research areas (co-occurrence of keywords analysis)

A preliminary network was created comprised of 16 nodes and 55 links, illustrating the main areas of research identified in BIM-FM research. However, this network has included some similarities among the nodes. In order to remove similarities, another analysis has been conducted to extract the most weighted nodes, resulting in 16 nodes and 26 links as shown in the following Figure (4).

Calculating network measures can be done by extracting certain information from the network itself through VOSviewer software. Degree centrality represents measuring the centrality of a node in a network using the number of connections, which indicates the effect of a node on other nodes.

According to Cobo et al. (2011), " a modified version of degree centrality, weighted degree in the network, takes into account the average mean of the sum of the weights of the links on all the nodes in the graph". In addition, he argues, "Involving the weight of links into calculating degrees will reveal the focal points or the level of involvement of nodes in a given network".

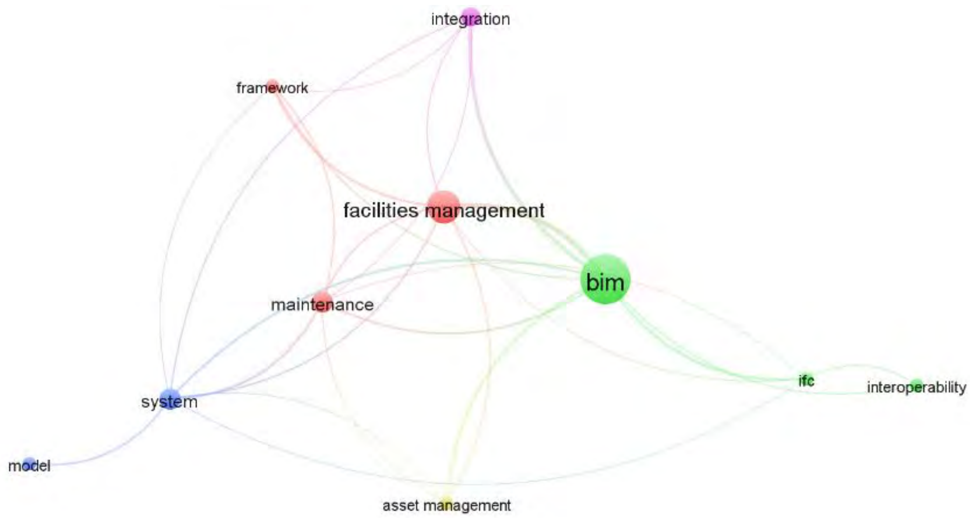


Figure (4) Main research areas after removing the similarities

Table (3) shows the results of analysis of the networks throughout VOSviewer output. The main research areas have been ranked according to the relative importance as shown in Table (3).

Table (3) Main research areas (co-occurrence of keywords analysis)

Research Area (Brief name/ Full Name)	Occurrences	Degree Centrality /Links	Weighted Degree Centrality/	Relative Importance
bim / BIM	20	8	16.00	1
facilities management / Facilities Management	11	7	10.00	2
system / System	6	8	6.00	3
maintenance / Maintenance	6	7	5.00	4
integration / Integration	5	5	5.00	5
framework / Framework	3	5	3.00	6
ifc/ IFC	3	5	3.00	6
asset management / Asset Management	3	4	3.00	7
Interoperability / Interoperability	3	2	1.00	8
model / Model	3	1	1.00	9

Several findings can be extracted from Table (3) and Figure (4) which, reflect gaps and issues within BIM-FM literature as follows:

1. There is a special focus on research areas such as ***bim***, ***facilities management***, and ***system***.
2. As an unexpected finding, there are less important research areas that focus on ***ifc*** and ***interoperability***. This reflects a lack of literature and attention by the researcher to these significant areas that are located in the bottom of the ranking. Hence, more research is required for Industry Foundation Classes and interoperability topics, which are considered the core of the connection between BIM and FM.
3. As illustrated in Figure(4), ***bim***, ***facilities management***, ***maintenance*** **,** ***framework***, ***integration, ifc, asset management*** *and* ***interoperability*** are linked together as one largest cluster in the network. These areas are positioned as central areas of research in BIM-FM and this might be attributed to the importance of BIM literature and the potential benefits of BIM in FM. In addition, Figure (4) shows the lack of research studies that integrate BIM and FM in general, which leads to a serious gap within the existing literature on FM. This might lead to the following conclusion: the integration of FM processes with BIM implementation requirements is still considered a barrier to more extensive implementation.

3. Top research outlets (direct citation analysis of outlets)

Direct citation analysis of outlets is very important for the interested researcher. Dealing with highly cited sources can be considered one of the best ways to reach accurate and reliable information in the certain domain. Accordingly, main cited sources in BIM-FM field and their relatedness are visualized through VOSviewer after the exportation of the related database from WOS. Figure (5) shows the main cited sources in BIM-FM field and their relatedness.

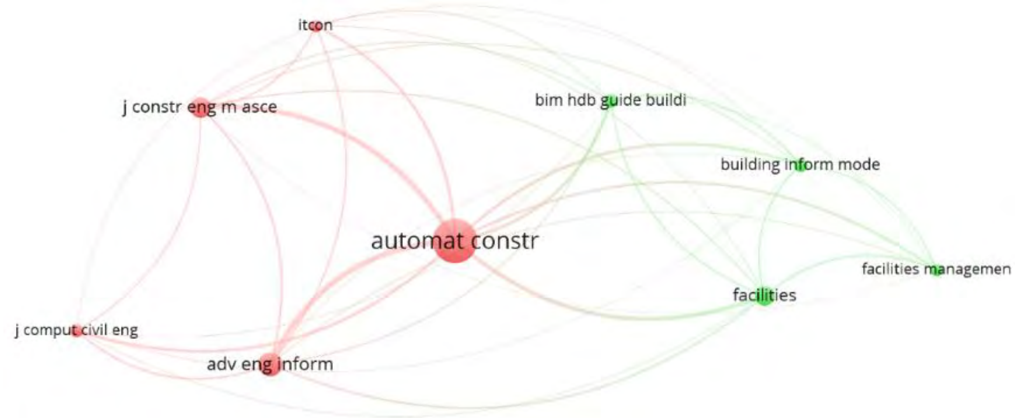


Figure (5), Network of prominent sources for publications in BIM-FM

Calculating network measures can be done by extracting certain information from the network itself illustrated in Figure (5), using the VOSviewer software as shown in Table(4):

Table (4), Top BIM-FM sources outlets

Source (Brief name/ Full Name)	Citation	Degree Centrality /Links	Weighted Degree Centrality/	Relative Importance
automat constr / Automation in Construction	139	8	70.67	1
adv eng inform / Advanced Engineering Informatics	40	8	28.72	2
j constr eng m asce /Journal of Construction Engineering and Management ASCE	30	8	26.06	3
facilities / Facilities	28	8	21.68	4
bim hdb guide buildi / BIM Guide	14	8	12.82	5
building inform mode / BIM Journal	13	8	12.12	6
j comput civil eng / Journal of Computing in Civil Engineering	12	7	10.48	7
itcon / Journal of Information Technology in Construction	11	8	10.23	8
facilities management / Journal of Facilities Management	11	7	8.75	9

Clearly, the Journal of Automation in Construction ranked in the first order with the highest number of citations and can be considered the most dominant source in BIM-FM research.
As shown in the table above, the flow of information starts from Automation in Construction with a Total Link Strength of 70.67, which is well above any other sources in the aforementioned table. In addition, the analysis shows that Journal of Construction Engineering and Management ASCE ranked 2nd with Total Link Strength of 28.72, while the Journal of Facilities ranked 3rd with a Total Link Strength of 26.06. Further, the strongest collaboration is between Automation in Construction and Advanced Engineering Informatics with link strength of 18.17. The second strongest collaboration is between Automation in Construction and the Journal of Construction Engineering and Management ASCE with A Link strength of 16.71.

4. Co-authorship analysis

- Authors

A Collaboration network analysis of authors in BIM-FM research has been conducted as shown in Figure (6). The results of the analysis showed that only Dawood, N., Kassem.M and Kang, T have two Authoring documents in the BIM-FM area. The other authors have one each. The top three cited authors were Becerik-Gerber, B., Calis, G. and Jazizadeh, F., with 80 citations each. The correlation among the authors is represented by the clusters shown below in Figure (6). Dawood, N., and Kassem.M has the strongest collaboration in BIM-FM research authorship.

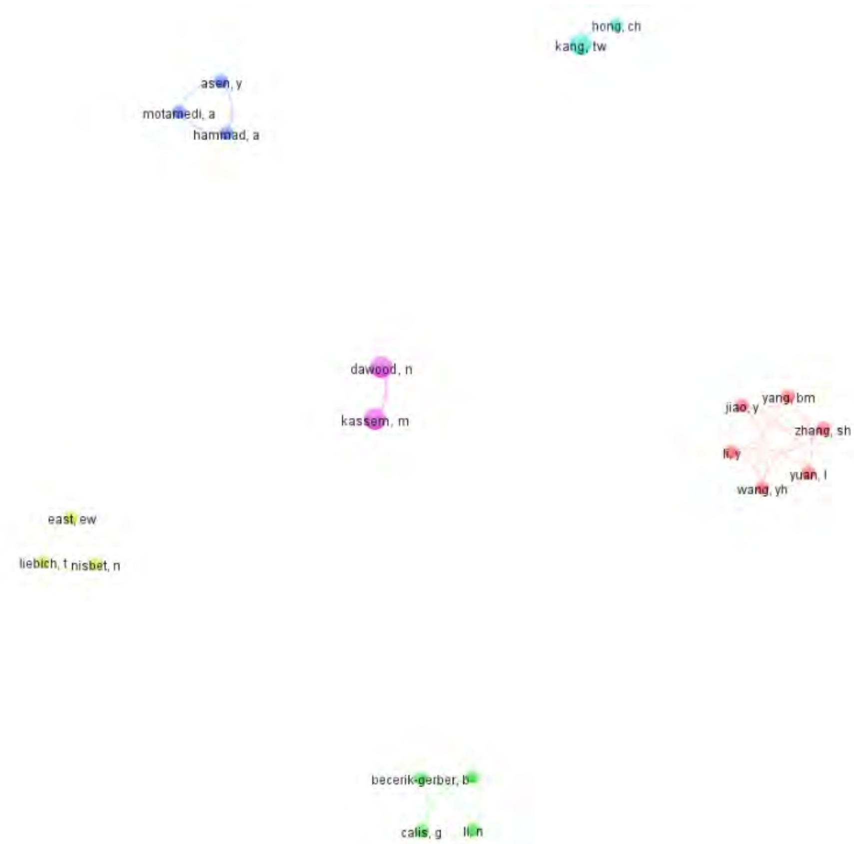


Figure (6) Collaboration network of authors in BIM-FM research

- Organizations

A Collaboration network analysis of organizations was created. According to Cobo et al. (2011), cited (Ding, 2011), this kind of organizations analysis "*benefits the field, particularly in terms of providing input into research partnership policy making* ".

As noted, some organizations in the network had no collaboration links among other organizations of the network such as Concordia University and the University of California. This needs to be noticed by these organizations in order to adjust their research policies, as they are located far from the dominant network of collaboration in BIM-FM.

Figure (7) Collaboration network of organizations in BIM-FM research

As shown in Figure (7), the red cluster consists of a number of organizations. This cluster can be zoomed up to get more information, as illustrated in the following Figure (8):

Figure (8) Cluster Zoomed

- Countries

To shed light on the most influential countries and to visualize the collaboration among them, a network analysis was conducted using VOSviewer. The number of documents and number of citations for each country were utilized as criteria to identify the degree of influence within this network, as shown in Figure (9). Accordingly, nodes sizes' are based on the degree of influence of each country within the aforementioned criteria.

Figure (9) Collaboration network of countries in BIM-FM research

As noted, some countries in the network had no collaboration links among other countries of the network such as Scotland, South Korea, Italy, and France. This needs to be noticed by these countries in order to adjust their research policies, as they are located far from the dominant network of collaboration in BIM-FM. As shown in the previous figure, the red dominated USA cluster consists of a number of countries. This cluster can be zoomed up to get more information about those other countries as illustrated in the following Figure (10):

Figure (10) Cluster Zoomed

Obviously, the USA ranked at the top with nine documents published in BIM-FM, while England ranked as second with seven documents. China gets third position with five documents. All the others get the bottom of the list with less than five documents each according to the circle size as shown in the figure. Smaller circles mean fewer documents and citations.

Conclusion

The current study focusses on research in the field of BIM-FM between 2003 to 2017. This area of study has attracted interest in the last few years, producing a number of studies and literature reviews. However, this research represents the first Scientometric Analysis of BIM-FM in the domain, in which 41 top-ranked documents were systematically examined using a Science Mapping method through VOSviewer software. The findings of this study show what has been achieved in BIM-FM topics, the potential gaps that need to be explored in the future, and the correlation among those findings. In addition, they help researchers understand which authors and journals to consider when dealing with BIM-FM topics.

Although this research has achieved a contribution in this area, there are some limitations. Firstly, the results of the analysis depended on the database that has been extracted from WOS, and therefore it carries any of WOS's limitations in terms of how much it covers of the published studies. Another limitation is that the study is based on an exploration of "what" questions, rather than “how” and “why”. Those limitations represent hot topics to be addressed in future research. Finally, it is clear that more research in the area of BIM-FM is needed. The lack of BIM studies in the FM phase put it behind the other phases such as design and construction. Hence, there is a real need to increase research effort in the BIM-FM area.

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BIM for collaboration and coordination

Haddy Jallow
(BIM Coordinator, Kier, Temsford, London , United Kingdom)

Suresh Renukappa and Subashini Suresh
(Faculty of Science and Engineering, University of Wolverhampton, Wolverhampton, United Kingdom)

Ahmed Alneyadi
(Abu Dhabi Police GHQ, Abu Dhabi, United Arab Emerates)

Abstract

Collaboration and coordination are massive factors when it comes to the construction industry. The construction industries have various parties within an organisation which have to work together to complete a project. As there are many teams within the organisations, communication is key as it could determine whether the project is productive.

Collaboration practices have not been the best in the industry as the industry has been massively paper based and with that, one team having data does not mean everyone has access to the data which may be vital for the project.

The Building Information Model has been mandated in the UK and all projects are to use a minimum of level 2 BIM. With BIM being previously aimed at building, the infrastructure sector has a lot to catch up on, BIM helps enhancing collaboration and coordination for an organisation, from visual aids to having a common data environment where everyone in the organisation can see all updated information and all data uploaded. Using the Building Information Model can help performance of an organisation as it does not only help collaboration for the organisation, but also assists with communication with the client and stakeholders. The purpose of this research is to investigate the issues the construction industry face when it comes to collaboration and how the use of a Building Information Model assists in provide better collaboration and coordination for an organisation.

Keywords

Building Information Model (BIM); Common Data Environment (CDE); Construction; BIM Implementation; 3D; 4D; 5D; 6D; 7D.

1. Introduction

The infrastructure sector is new to the BIM world, and with level 2 being mandated in the UK, the infrastructure civil sector is seeing the benefits they can gain from the use of a Building Information Model.

Collaboration between teams in the construction industry is becoming more complicated, and with collaborative practices being highly important in the industry and being essential to the success of construction projects. Recently the construction development delivery has been changing as there is a high demand in partnership with Joint Ventures and also public and private partnerships, which increases the high importance of collaboration (Akintoye, 2007).

With the recognition of the importance of adopting a collaborative BIM approach, the UK Government has mandated that fully collaborative Building Information Models (BIM) is to be used for all public-sector projects. A fully collaborative BIM would contain a 3D model with all asset data and documentation linked into the model. Prior to the required BIM processes, the UK construction industry was highly document focussed. There are four levels of BIM maturity with BIM Level 2 being mandatory in the UK;

Level 0 BIM
This is the simplest of all the levels, it consists of converting paper drawings to 2D CAD drawings and the output is simply distributed along the parties by paper or electronically (NBS, 2014).

Level 1 BIM
Level 1 is a combination of 3D CAD models for concept work and 2D for drafting documents and information about the product. The CAD models are managed with the use of BS 1192:2007 and the data share electronically is obtained by the common data environment (CDE) which is usually managed by the contractor (NBS, 2014). This level is mostly being used at present even though it does not contain the collaborative aspects.

Level 2 BIM
This level is the level of BIM required by the government by 2016. It is operated by collaborative practices, all parties work on their own 3D model which is not necessary a shared model however the design information shared through the same file format allowing the organisations to be able to input data and all check on it. Each party using the CAD software should be able to access the file formats through IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange (NBS, 2014).

Level 3 BIM
Level 3 BIM uses a single shared model and is a fully collaborative process. All of the parties involved and use the same model accessing and changing it if required, this allows the risks to be reduced by reducing the conflict of information. This level is the governments' requirement by 2019 (NBS, 2014).

The Building Information Model has been claimed to be the future of engineering (Eastman, 2008). In the construction industry, we could say some BIM tools were being used before the UK government mandated its use, however the digital devises of BIM were mainly used to focus on specific design tasks and not used for collaboration and coordination purposes (Kiviniemi, 2008).

BIM is a collaborative process, the purpose of BIM as a collaborative process being mandated in the UK is that its collaborative practices assist in providing better design and also saving costs while providing time effective designs through improving communication between the different disciplines, clients, contractors, stakeholders, etc. the aim of this paper is to investigate the issues based on collaboration and cooperation in the construction industry and to look at the Building Information Model and how its tools can be utilised in order to improve collaboration within the industry.

2.0 Related Studies
This section includes current studies that are concerning the Building Information, topics include; BIM Implementation, BIM asset procurement strategy and 4D BIM.

2.1 BIM Implementation

The implementation of BIM is more of a business decision rather than a technical one (Smith, 2009) as the implementation of BIM provides the different parties a better way of communication and also improves the quality outcome by allowing better decision making which can lead to reduced time and cost.

Implementing BIM does not only affect the construction process but also impacts the business processes. When chosen to implement BIM, business owners need to be able to visualise the future benefits and also see the positive outcome it can have on business relationships.

BIM must be implemented in the right way, businesses should analyse the internal business process, for example they are to evaluate the type of business; whether design, construction etc. through doing this process, businesses can see if their business processes are a part of the systems and if the information provided with the model can be utilised by the different parties in the organisation (Smith, 2009).

2.2 BIM asset procurement strategy

The adoption of BIM is not one that can just happen; a BIM strategy should be in place. A BIM strategy has to be clear defining the information management processes.

There are 5 key elements to a BIM strategy which are as follows;

- *BIM based process map development*

This provides guidance on the BIM implementation plan. As previously mentioned, the implementation of BIM is more of a business decision rather than a technical one, so the business processes of the organisation has to be reviewed. The process is needed to be established and support the information delivery cycle.

- *EIR (Employee Information Requirements)*

This is where the client (Employee) provides the document indicating their output requirements from BIM.

The EIR is a very important document which is defined in PAS 1192-2 and is a pre-tender document. The aim of an EIR is to confirm that the suitable information in the appropriate format is used from the pre-contract stage and throughout the BIM process.

- *BEP (BIM Execution Plan)*

The BIM Execution Plan it thought to be a reply to the ERI. The idea of a BEP is to aid the management of information for the project.

The BEP is developed both in the pre-contract and post-contract stages. A BEP details the deliverables of the project and the requirements of the information exchange format. A BEP also includes an MIDP; Master Information Delivery Plan which includes all different aspects of the model, and a TIDP; Task Information Delivery Plan which are individual delivery plans for the different aspects of the model.

- *BIM roles and responsibilities*

The roles and responsibilities are then defined. The types of roles defined are as follows;

- Employee Representative
- Project Delivery Manager
- Project Information Manager
- Task Information Manager

Just to name a few.

- *CDE*

Finally, the Common Data Environment. A CDE is to be used throughout the project where all disciplines share information, please see chapter 4.3.

2.3 4D BIM

There are five dimensions of BIM which are as follows:

3D BIM

3D BIM includes the formation of a 3D model with asset data, this allows us to see things that are not visible on a 2D drawing, it allows clash detection to be possible and provides better visualisation including walk trough's and assists in communicating with the parties and clients (Carpenter-Beck, 2017).

4D BIM

With 4D BIM, the programme is added to the model, this makes the model time-based and allows construction planners to use simulations to view their workflows and see if they are feasible and is any changes to the work flows are to be done to allow for a faster construction (Carpenter-Beck, 2017).

5D BIM

5D BIM is where cost is added to the programme, this assists estimators in providing the impact of cost with different design schedules, allowing them to choose the most cost effective and feasible approach to save time and money (Carpenter-Beck, 2017).

6D BIM

As mentioned before, BIM assists the asset throughout its lifecycle even after construction. 6D BIM is the concept of having the asset data on the model. As-built information can be linked to the model as well as ongoing maintenance works data which can help in lowering of maintenance costs as data about the asset is already know so damages to be fixed can be prepared for (Carpenter-Beck, 2017).

7D BIM

7D and 8D BIM has been talked about, however the BIM processes have not yet been defined (Carpenter-Beck, 2017).

Figure 1 illustrates the 5 dimensions of BIM:

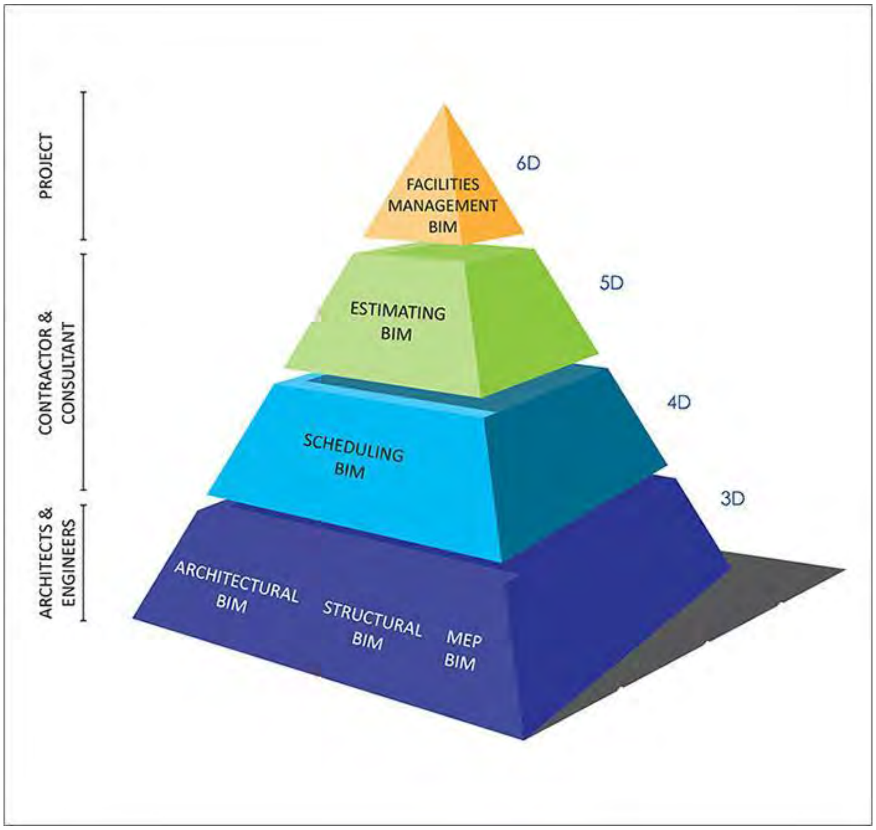


Figure 1 Dimensions of BIM

Source: (The Master Builder, 2014)

The use of 4D BIM simulations can provide various benefits t a project. With the model being linked to time, planners can utilise this to visualise their work plan. Most planners have difficulty going on site to see if their work plan is possible and without obstructions, with the 4D model, planners do not have to go on site as they can visualise the site on the model.

Having a 4D model also benefits the on-site team. With the programme being linked to the mod, the on-site team can benefit from being able to understand the work plan through visualisation rather than looking at the work plan on a Gantt chart and trying to understand how to carry out the works.

3.0 Methodology

With collaboration being an important factor in the construction industry, collaborations and coordination practices should be investigated to find better practices which can lead to improved data management and coordination.

This study comprises of a mixed method approach, identifying how the use of the Building Information Model improves collaboration and coordination in the construction industry. Case studies were observed at and semi structured interviews were also conducted.

Semi-structured interview is a qualitative method that is a combination of pre-determined set of questions which the interviewee is given the opportunity to explore a variety of responses. ***Qualitative research*** is mainly described as an empirical research. This form of research is utilised to obtain knowledge and understanding of primary reason, opinions and motivations (Wyse, 2011). This form of research provides an awareness of the issue or assists in providing ideas for the quantitative research. Qualitative research is a method of uncovering opinions and providing a deeper insight within the problem. This method of research is obtained through the use of unstructured or semi-structures practises which mainly include focus groups, individual interviews where the respondents are selected in order to fulfil a provided part (Wyse, 2011).

A typical logic of a qualitative design was derived by Kalof is demonstrated in Figure 8, (Sengul, 2005):

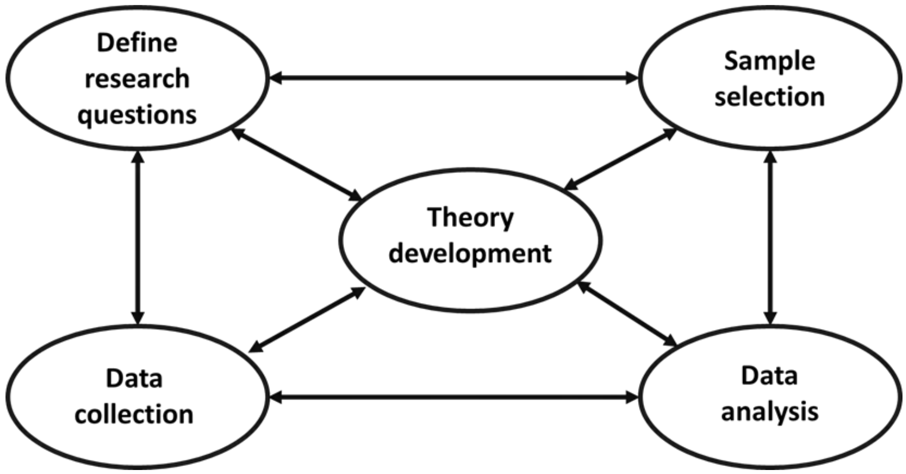


Figure 2 Overview of general qualitative research process

Source: (Sengul, 2005)

Prior to the semi-structured interviews, the research was prepared for, this was done through steps:

Literature review
A literature review was conducted understanding the collaboration practices in the construction industry and the data management practices along with the use of BIM.

Research questions
Following the literature review, the research questions were then underpinned which are as follows:

- What is the current state of collaboration practices in the construction industry?
- Do existing BIM processes assist in better collaboration?
- Is BIM worth implementing for the purpose of improving collaboration?

Interviews
Following these research questions, an idea of an interview guide was obtained. The interviews were targeted at BIM experts that have been in the industry long enough to have an idea of using how using BIM has improved previous collaboration practices.

The interviews were undertaken through phone interviews as the BIM experts are all over the UK, hence distance was an obstacle.

4.0 Results

The findings were divided into sub categories which are as follows:

- Current collaboration issues
- Collaboration practices being used
- Use of a Common Data Environment (CDE)
- Issues with BIM implementation

- BIM allowing better collaboration

4.1 Current collaboration issues

Collaboration is a team effort. And with construction projects having different teams in one organisation, it is an important factor.

From the findings, collaboration is difficult when everyone is not on the same page. Simple communication such as emails can be classed as collaboration and sharing information, however the use of BIM requires tools and electronic document management systems to achieve BIM level 2.

The main factors affecting collaboration within the construction industry are people related. Prior to BIM level 2 being mandatory, collaboration was not very well handled. With most of the work being paper based, documents could be lost and with the construction industry being busy, people on certain jobs would forget what was previously done hence loss of information.

The main factors that affect people's collaboration practices are defined in table 1:

Table 1
Collaboration Issues; People

Theme	Results
Different teams (people)	• Absence of trust • Lack of commitment • Fear of conflict • Human errors • Inattention to results

4.1 Collaboration practices in use

All the interviewees are currently using BIM level 2 within their construction projects as is has been mandated by the UK government.

BIM level 2 requires a 3D model for each of the project teams and it is operated by collaborative practices, with BIM level 2, there is still a lack of a single source of data however any data collected which would be as-built would be available to share, which enables a federated model to be created.

This brings us to our third result topic;

4.2 Use of a Common Data Environment (CDE)

BIM level 2 requires a common data environment to be available to all teams within the organisation. The findings show that all organisations are using a CDE, however it is not proving very effective.

As mentioned before, people with lack of trust and commitment may be reluctant to put data onto the CDE which is required and necessary for the BIM process to become a collaborative one.

A few of the interviewees find the CDE to be a good way of communicating. They have found that with all the project data being on one data environment, it was easily accessible and all project data was stored and when needed was easy to find and reflect on the data, whether it be for outstanding works or defects to be looked at again.

4.3 Drawback of BIM implementation

When it comes to collaboration, the difficulty is within the team. If the architect uses the model to build the design, it might not be designed to aid in construction as it may not have enough detail for the right use. (Hardin, 2015)

• *Preventing industrial hacks*

These days, the cloud has a lot of information and with the growth of cybercrime, companies using BIM have to make sure that the programme is very well secure and meet the UK Government CESG cloud Security Principles. (Mason, 2014)

• *Programmes' ability to work with other software*

With the programmes difficulty to work with other software, the company using BIM should consider how they are going to "consolidate, interpret and utilise the increasingly mountainous volumes of data" (Mason, 2014).

• *Management of the information*

BIM has a major challenge in managing the large volumes of information which are very detailed, these should be taken care of responsibly according to Hugh Boyes, Cyber Security Lead, at IET (Mason, 2014).

• *Economy and skills gap (software cost)*

Of course, with this technology, data analysts, engineers, architects and others to use the programme must be familiar with it and know how to operate BIM, however most engineers registered with the ICE (about 40%) (Mason, 2014) are over the age of 60 which would be a challenge in learning the software and is why the industry is encouraging the next generation to get into engineering. Costs for the programme include the purchasing, licence and training and the contractor may also need to update computer systems to be able to use the BIM programme.

• *More work at the start*

As BIM would require training for the prime contractors, designers and so on, it requires a lot of effort at the beginning of the project. These parties need a sit down to produce a collaborative model (Carlin, 2010).

• *Disruptive*

One of the advantages of BIM is that changes can be made easily, however this can also be a disadvantage. If dimensions of materials are checks and an order of material is made, changes to the design can be a difficulty as the order would take a couple of weeks to be delivered and if changes were made that would go to waste leading in an input for another batch of materials to suite the design (Carlin, 2010).

• *Stakeholder's software compatibility*

For the stakeholders to have compatibility, it is not necessary for them to be using the same software platform, however it is necessary for the software being used by each stakeholder to be compatible as they would be able to exchange data and files. The issue that can arise from BIM is incompatibility between software's for these stakeholders. This however has a solution, as the IFC software programme enable compatibility between BIM and other software's (Dowhower, 2010).

4.4 BIM for better collaboration

BIM can be used in several ways to enhance collaboration within the construction industry. Most of the interviewees identified various ways in which they have used both the Building Information Model and its processes and tools to improve collaboration.

The Table 2 summarises the benefits found improving collaboration through the use of BIM;

Theme	Factors
On-site team	• Visualisation through 4D; • Information gathering for construction; • Re-work reduced • Clash detection
Stakeholders / client engagement	• Visualisation • Walk through of job • Confidence gained
Overall	• Reduction of changes and errors • Improved productivity • Vital information being available to be viewed • Improved quality

On-site team

The on-site team on one of the projects found that with the use of BIM, using a 4D model made it easier for them to understand the programme produced by the planners. With the 4D model, they could visualise the work plan and understand how the works were to be carried out on site.

With the use of the 3D model the on-site team also found it very useful as they would ask the BIM team for cross sections which they used for gathering information about what is required and if it would be feasible, this pre- planning and discussion with the cross sections allowed the reduction of re-works as they would know what to expect when going to carry out works and impossible tasks can be spotted. With the use of these visual aids, it was possible for the designs to also be reviewed by the different teams in the organisation and the best solution would be chosen.

Stakeholders / clients

One of the projects in which the BIM manager was interviewed outlined how the use of BIM assisted in stakeholder and client meetings.

The BIM model was used in meeting with the stakeholders with the Traffic management proposal for the finished works, this gave stakeholders an insight as to how the traffic management was to be set up when works were on going which gave them the opportunity to communicate with the teams on if the traffic management would work or now.

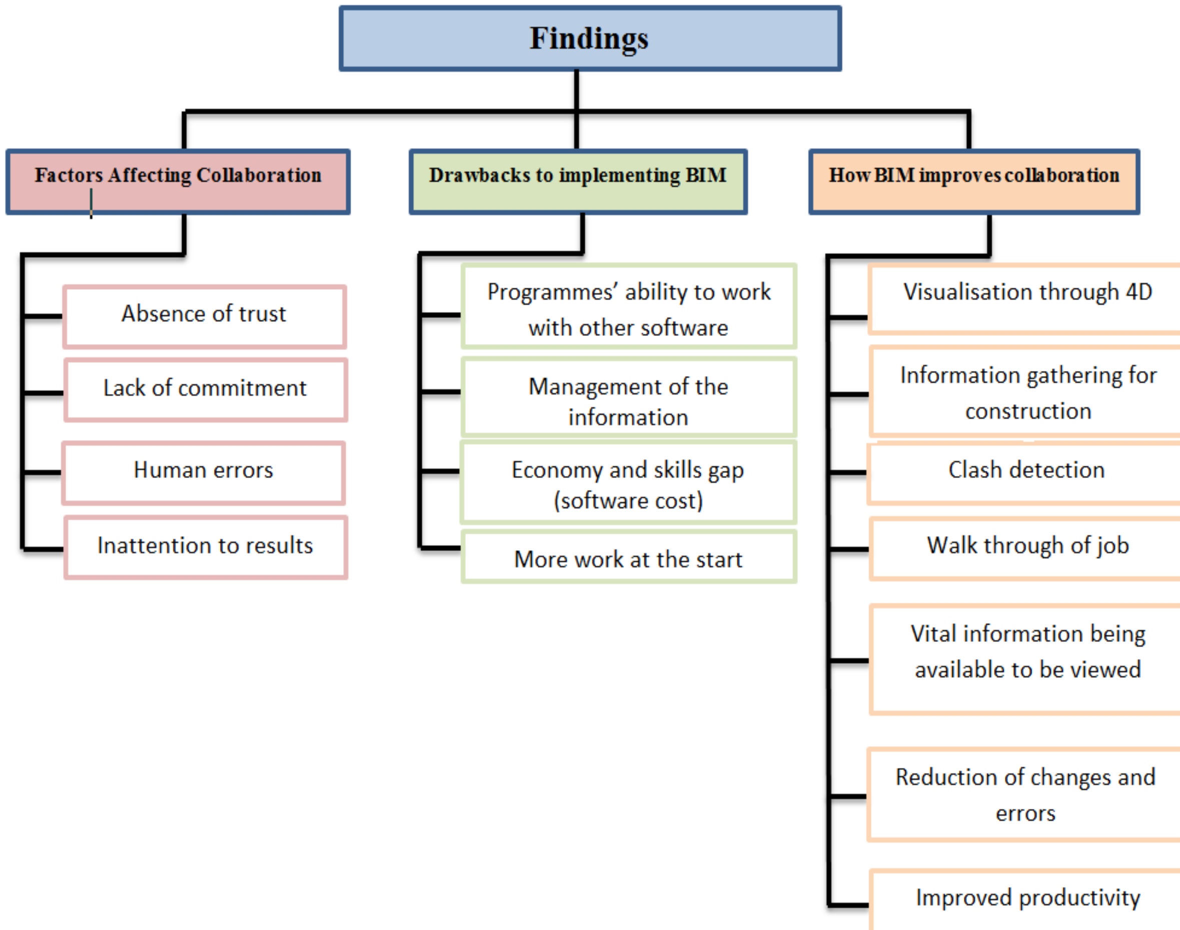
A walk through of the job was also shown, the project was a smart motorway scheme expanding a 3-lane motorway with a hard shoulder into an all lanes running motorway with ERA's (Emergency Refuge Areas).

With this walk through, clients were able to see the final product before the project was completed, allowing input from the clients to improve the projects decision making.

Overall

BIM improves collaboration overall according to the interviewees, with communication improved, this brings a lot more benefits such as reduction of changes and errors. When ideas are communicated, with the aid of the model and visualisations, these different ideas can be tested out choosing the most efficient and cost-effective solution.

The overall results of the findings are summarised in Figure 3;



5.0 Discussion

Implementing BIM will not solve all issues relating to collaboration if not implemented in the right way.

There are obstacles which were found within this research when it comes to the implementation of BIM, with BIM being a missive process, the right and compatible software is to be used. Software's used, if not compatible may prove to be an issue as if the software's cannot work together the implementation of BIM would be a difficult process.

Issues raised based on collaboration have been mainly focussed on people, with BIM, if implemented properly, the issues should be solved however with the construction industry mainly consisting of the older generations who have been in the industry for more than 20 years, they are used to their ways, the change can be difficult. Prior to BIM being mandatory, the industry was highly paper based and the change from paper based to IT based can be difficult. This change will require a lot of training at the start of implementation; the training would also only work if the training is practiced.

Although there is concern on whether the implementation of BIM is worth the costs at the start of the job, with collaboration and coordination not being a story factor in the construction industry, it would be necessary and would allow the organisations to achieve a more cost effective and efficient way of construction leading to a more productive project.

6.0 Conclusion

The construction industry has many factors that determine good productivity. Collaboration is an important factor when it comes to high performance and productivity.

Collaboration practices have not been the best and there are a few influences that mainly affect the process leading to poor collaboration. In the industry, people are reluctant when it comes to collaboration, whether it is lack of trust or human error.

BIM tools can be used to improve collaboration and coordination in the construction industry, with visualisation being the best way of communication as people understand visuals. Producing 4D models, cross-sections, 3D visuals etc. helps communication to be enhanced within an organisation.

BIM can improve collaboration for all different parties within an organisation from the on-site team to the client. Besides producing visual aids, level 2BIM also requires a common data environment which all data is kept, hence and parties have access to all data and once updated, all updates would be available minimising loss of translation as all teams can see changes immediately.

BIM experts would recommend the use of the Building Information Model as they have found it improves collaboration and coordination within their individual organisations.

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Awareness and Adoption of Light Gauge Steel (LGS) Technique in the Construction Industry

DOSUMU, Oluwaseun
Sustainable Human Settlement and Construction Research Centre
Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
Oluwaseundosumu97@gmail.com

AIGBAVBOA, Clinton
Sustainable Human Settlement and Construction Research Centre
Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
caigbavboa@uj.ac.za

THWALA, Wellington
Sustainable Human Settlement and Construction Research Centre
Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
didibhukut@uj.ac.za

MBOYA, Unathi
Sustainable Human Settlement and Construction Research Centre
Faculty of Engineering and the Built Environment, University of Johannesburg, South Africa
unathi.mboya@gmail.com

Abstract
Light Gauge Steel (LGS) construction has been a well embraced building technique in the developed countries for many years. However, it is an unpopular method of construction in the developing countries, including South Africa. The aim of this study is to gain insight into the level of awareness and adoption of LGS technique in the construction industry. The survey research design was adopted for this study. Questionnaire was administered on large contracting and consulting firms in South Africa using the random sampling technique. The data for the study was analysed with frequencies, percentages, mean item scores and t test statistics. The results of the study indicate the perceived percentage level of awareness and adoption of LGS technique in the construction industry. The mean ratings of variables according to consultants and contractors were also indicated in the study. It was also concluded that light gauge steel is adopted for construction in South Africa, but it is mostly used as wall elements. The study recommends that, there is need for more awareness on the usefulness and need to adopt LGS for construction industry.

Keywords
Conventional construction, construction professionals, green building technique, Light gauge steel.

1. Introduction

Light Gauge Steel (LGS), also known as Lightweight Steel is a cold-rolled steel product, commonly available in the shape of flat sheets, angles, or channels and often used to frame non-structural partitions (Lapedes 1978). LGS structures are outstanding buildings in Australia, the United States and Europe. It has been in use for over 50 years now (Barnard, 2011). It is utilized for all types of structures, be it public, private, offices, schools, hospitals, churches etc. In spite of the long years of adoption of LGS, it is surprising that it is not a popular construction technique in developing countries, including south Africa. Some of the reasons may be attributed to the awareness of the construction technique in developing countries. Hence, this research investigates the level of awareness and adoption of LGS construction technique in South Africa.

2. Literature Review

Developing the awareness of LGS is one of the essential requirements of South African Light Steel Frame Association (SASFA) for sustainable and environment-friendly building strategy. The intended interest groups for LGS include designers, quantity surveyors, engineers, developers, material suppliers and clients. The Southern African National Standards (SANS) is responsible for ensuring that standard materials are used for construction. According to Kozlovská and Spisáková (2013) and Hauke, et al. (2016), there is little knowledge on the outcome of recycled materials such as LGS. However, AISI (2010) noted that LGS has transformed into an always wanted construction material. Despite the crave to adopt LGS for construction in many parts of the world, its awareness in developing countries like South Africa remains low. In view of this, the Steel Market Development Institute (SMDI) took the step to improve the awareness of LGS in the construction business and influence different companies to upgrade to LGS (AISI, 2010).

The LGS framed structures were recommended as the general construction technique in the Building Standard Law of Japan (Hayashi, 2012). The National Construction Association (NCA) recognized innovative approaches for achieving affordable housing at the state and local levels (Schroder, 2010). Mittal *et al.* (2008) noted that, when a client decides to use steel for construction, the decision was made with great knowledge of the awareness of the usefulness of each of its components. Mittal et al. (2008) further explained that the construction team was aware of the fact that, steel is a type of recyclable material which offers importance to the building industry.

Barnard (2011) stated that there is need to have construction principles for LGS frameworks just as there are frameworks for stone work and cement. Akinboade and Mkowena (2012) noted that, new construction innovation is always more expensive than what it replaces. Building and Construction Authority (2016) explained that LGS could be used for ceiling joist, floor joist, wall stud, structural sheathing, load bearing studs, cold-forming, flange flat strap, galvanised steel, clip angle, framing, non-load bearing wall and rafter. Chini and Gupta (1997) added wall studs and roof trusses to the list of where LGS can be used.

LGS can also be used as lightweight cladding, curtain wall and drywall framing (Kumba Iron Ore, 2013). The Japan Iron and Steel Federation (2012) noted that, LGS was adopted as exterior wall panels, wall framing, partitions and roof truss. Hayashi (2012) further explained that LGS could be utilized for industrial structures such as truss rooftop framework or complete frame. Coskun (2007) stated that LGS can be used in segmental sizes of hot rolled steel for framing structure or as additional building parts.

Schroder (2010) informed that LGS may be used as a floor framing system with all types of known flooring materials such as plywood, floor tiling, Oriented Standard Board (OSB) concrete-filled steel deck and even fibre reinforced cement board. According to Lyons (2009), the Americans have changed from building of homes with the timber frame to cutting and assembling of structural steel frames with LGS. Coskun (2007) affirmed that, adopting LGS as an alternative method of construction is a positive and effective choice for construction. Despite the beneficial uses of LGS, it has not gained popularity in developing countries including South Africa. This study seeks to investigate the level of awareness and adoption LGS in the construction industry.

3. Research Methodology

In this research, the quantitative and qualitative methods were used. The study was conducted within Johannesburg and Cape Town. The questionnaire was served on construction professionals (contractors/builder, construction managers, architects, quantity surveyors, project managers and engineers) that were engaged on LGS projects. The construction professionals were located within various construction companies in Johannesburg and Cape Town. The questions used to obtain information on the study was based on a 5-point Likert scale. The purposive sampling technique was used for this study because there are not many LGS based projects in the South Africa, hence the need to purposely serve the questionnaire on LGS projects. The frequency, sum and Mean Item Score (MIS) were used to analyse the data for the study.

4. Data Analysis

Table 1 displays the profession of the respondents. Results show that 25.0% of the respondents were architects, 16.67% were project managers, 13.89% were developers, 8.33% were quantity surveyors, 5.66% were engineers and 30.56% were in other professions.

Table 1: Profession of respondents

Profession	Percentage
Architects	25.00
Project managers	16.67
Developers	13.89
Quantity surveyors	8.33
Engineers	5.66
Others	30.56
Total	100

Table 2 displays the Professional bodies of the respondents. Results show that 52.78% are with SASFA; 16.67% are with SACPMCMP; 11.11% are with SACQSP and Other professional bodies; 8.33% are with CEA.

Table 2: professional body of respondents

Professional body	Percentage
SASFA	52.78
SACPMCMP	22.78
SACQSP	16.11
Others	8.33
Total	100.00

Table 3 displays the type of civil engineering projects handled by respondents. Results show that 70% were structural, 20 % were roadworks and 10% were other civil engineering projects.

Table 3: type of projects handled by respondents

Type of project	Percentage
Structural woks	70.0
Roadworks	20.0

Other civil engineering	10.0
Total	100.0

Table 4 explores the level of awareness of Light gauge steel construction in the construction industry. The results indicate that, among the uses of LGS, respondents' awareness is in the order of wall framing (3.97), floor joist (3.94), interior wall panel (3.86), load bearing wall stud (3.86), and structural sheathing (3.81). The areas of use with least awareness are Deck/slab (2.92), mounting joist (2.67), binder (2.58), heel (2.58) and node (2.47) respectively.

Table 4: Awareness of Light Gauge Steel construction

Areas of use of LGS	N	Mean	Std. Deviation	Rank
Wall framing	36	3.97	1.230	1
Floor joist	36	3.94	1.413	2
Interior wall panel	36	3.86	1.334	3
Load bearing wall stud	36	3.86	1.222	4
Structural sheathing	36	3.81	1.191	5
Exterior wall panel	36	3.81	1.431	6
Rafter	36	3.78	1.290	7
ceiling joist	36	3.75	1.339	8
Strut	36	3.72	3.591	9
Non-load bearing wall stud	36	3.53	1.362	10
Purlins	36	3.44	1.403	11
Lower floor top plate	36	3.28	1.485	12
Upper floor bottom plate	36	3.28	1.386	13
Kingpost	36	3.22	1.456	14
Bottom track	36	3.19	1.431	15
bottom chord/tie beam	36	3.17	1.521	16
Floor stud	36	3.14	1.496	17
Ridge	36	3.11	1.469	18
Top track	36	3.03	1.483	19
top chord	36	3.00	1.394	20
Web	36	3.00	1.549	21
ceiling batten	36	3.00	1.474	22
Side beam	36	2.97	1.444	23
Cross beam	36	2.97	1.464	24
Deck/slab	36	2.92	1.628	25
Mounting joist	36	2.67	1.394	26
Binder	36	2.58	1.381	27
Heel	36	2.58	1.381	28
Node	36	2.47	1.298	29

Table 5 indicates the level of adoption of light gauge steel construction in the construction industry. Floor joist was the most adopted LGS (3.64) followed by interior wall panel (3.61), wall framing (3.53), structural sheathing (3.50), load bearing wall with stud (3.47). the least adopted LGS are mounting joist (2.39), cross beam (2.39), top chord (2.33), node (2.28) and binder (2.19) respectively.

Table 5: Adoption of Light Gauge Steel construction				
Areas of use of LGS	**N**	**Mean**	**S.D**	**Rank**
Floor joist	36	3.64	1.313	1
Interior wall panel	36	3.61	1.460	2
Wall framing	36	3.53	1.424	3
Structural sheathing	36	3.50	1.384	4
Load bearing wall stud	36	3.47	1.362	5
Exterior wall panel	36	3.47	1.576	6
Non-load bearing wall stud	36	3.28	1.523	7
Rafter	36	3.14	1.417	8
Lower floor top plate	36	3.06	1.286	9
Ceiling joist	36	3.03	1.444	10
Kingpost	36	2.89	1.326	11
Web	36	2.89	1.563	12
Purlins	36	2.86	1.417	13
Upper floor bottom plate	36	2.81	1.369	14
Floor stud	36	2.81	1.348	15
Strut	36	2.78	1.476	16
Bottom track	36	2.78	1.290	17
Top track	36	2.75	1.204	18
Ridge	36	2.64	1.355	19
ceiling batten	36	2.58	1.500	20
bottom chord/tie beam	36	2.58	1.481	21
Side beam	36	2.56	1.443	22
Deck/slab	36	2.50	1.540	23
Heel	36	2.42	1.538	24
Mounting joist	36	2.39	1.420	25
Cross beam	36	2.39	1.337	26
top chord	36	2.33	1.454	27
Node	36	2.28	1.323	28
Binder	36	2.19	1.451	29

5. Discussion of findings

These findings are in total agreement with the findings of APTA (2005) that LGS in construction are used for ceiling joist, floor joist, wall stud, structural sheathing, load bearing studs, cold-forming, flange flat strap, galvanised steel, clip angle, framing, non-load bearing wall and rafter accordingly. The results are also in agreement with the findings of Chini and Gupta (1997) which states that LGS is used for wall studs and roof trusses. The Japan Iron and Steel federation (2012) explained that LGS was adopted for exterior wall panels, wall framing, partitions and the roof truss. Therefore, going by the findings of this study, the awareness of LGS is highest on wall elements rather than roof and floor elements. The implication of the above findings is that, construction professionals in the construction industry need to get more awareness on the use of LGS as roof and floor elements.

6. Conclusion

Based on the findings of the study it was concluded that respondents' level of awareness of LGS construction is slightly above average; however, they are more aware of the use of LGS as wall elements and not floor and roof. This is evident in their ratings as wall framing has the highest mean score. In line with the level of awareness, the results of the study show that respondents adopt LGS mostly for wall elements. Therefore, the study concludes that LGS is only currently used for wall elements in the South African construction industry. In addition, the study concludes that, adoption of LGS is determined by the level of awareness of LGS. Therefore, the study recommends that, more awareness should be created on the use of LGS for wall, roof and floor respectively. Organizations should have regular workshops and conferences to enlighten more people on the awareness of LGS for construction.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

Challenges Associated with Nominated Suppliers Procurement (NSP) Method in the South African Construction Industry

Oluwaseun Dosumu
(*Sustainable Human Settlement and Construction Research Centre University of Johannesburg, South Africa*)
oluwaseundosumu97@gmail.com

Clinton Aigbavboa
(*Sustainable Human Settlement and Construction Research Centre University of Johannesburg, South Africa*)
calgbavboa@uj.ac.za

Wellington Thwala
(*Sustainable Human Settlement and Construction Research Centre University of Johannesburg, South Africa*)
didibhukut@uj.ac.za

Nxumalo Thandokhule
(*Sustainable Human Settlement and Construction Research Centre University of Johannesburg, South Africa*)
cedriclungelo@gmail.com

Abstract

Nominated Suppliers procurement is a method that is being currently embraced in South Africa. However, it is unclear how the method is being administered in the construction industry. The aim of the study is to gain a reputable knowledge into the challenges associated with Nominated supplier's procurement method in the South Africa construction industry. Out of the 90 questionnaires that were distributed, 67 (giving a response rate of 73%) were retrieved and used for the study. Data collection was based on random sampling technique from construction professionals and merchants such as project managers, clients, manufactures, suppliers, engineers and quantity surveyors. The findings reveal that inadequate planning and scheduling by the supplier, fluctuation of prices associated with the prevailing supply–demand cycle and lack of commitment by material supplier are some of the challenges of nominated supplier's procurement method in South Africa.

Keywords

Nominated suppliers, procurement challenges, construction industry, South Africa

1. Introduction

There are two familiar, but different types of subcontracting and they include domestic and nominated subcontracting. Al-Haij and Skaik (2013) noted that the construction industry has been using these methods of subcontracting for quite a long time. Virtually all the types of procurement routes know about these subcontracting methods. Many mega projects are not usually completed without the involvement of subcontractors and suppliers. Brook (2008) highlighted that some main contractors have less expertise and competencies for which they are compelled to subcontract part of the project to specialist subcontractors and engage some suppliers to supply some of the construction materials.

Since the early 1990s', there has been growing interest in nominated contracting practices with a view to understanding and characterising deficiencies, and proposing solutions that are aimed at improving the coordination of NSP in the construction industry (Segerstedr & Olofsson, 2010; Eriksson, 2010). Chiang (2009) noted that, there is a huge need for expertise to cope with the complex and large–scale construction projects that are taking place around the globe. The needed expertise ensured that projects and their executors are faced with challenges that can significantly affect construction projects. one of the methods of overcoming the huge challenges of complex construction projects is the adoption of nominated supplier for materials. This is the current practice in south Africa on many formal construction projects. NSP method is however facing various challenges that are militating against it success in the construction industry. The investigation of these challenges is the focus. This will enable construction professionals and other stakeholders to know the areas of concentrate effort in their bid to ensure that NSP is a success.

2. Literature Review

In the study of Yang et al. (2013), it was suggested that NSP strategy is vital for the mitigation of risks associated with unavailable construction materials. Other necessary steps to overcoming material problems include establishment of better materials management systems and improvement of the understanding of NSP internal requirements. These steps reduce the time spent on a project and increases its quality. It may also ensure that projects are completed at the agreed cost. With all these benefits, NSP still faces challenges. There is also scarcity of researches on the challenges of NSP in the construction industry.

Akogbe et al. (2013), Mpofu et al. (2017) and Nguyen et al. (2015) found that, material supplies on construction projects need to be accurately planned and executed to avoid material shortage or excessive material inventory. Baloyi and bakker (2011) supported the statement by stating that increase in cost of materials is the largest contributor to cost overrun in some stadia construction projects. This assertion is similar to that of Niazi and Painting (2017) who noted that fluctuating market price plays a huge role in poor construction project performance.

Construction materials constitute more than 40% of the total cost of construction projects (Patel et al., 2011). Construction delay, which is usually as a results of supply problem occurs in many countries, especially on public projects (Hwang et al., 2013). Trauner (2009) stated that the causes of delay include unavailability of construction materials in the market, modification in materials type and specifications during construction among others. In addition, Jarkas and Haupt (2015) found that, unavailability or shortage of construction materials, instability of prices related to the material supply–demand cycle and postponement of material procurement by contractors are some of the challenges of nominated suppliers. Safa et al. (2014) commented that, procurement and management of construction materials include challenges identified with lessening list, rapid conveyance and expanding of the control of materials which diminishes project cost.

From previous researches, Al Hajj and Skaik (2013) claimed that the challenges of using nominated suppliers are cost uncertainty, late nomination of supplier, failure of the parties to enter into subcontracting agreement, argumentative relationship with main contractor, uncertainty of the relevant contract provisions and nominated suppliers default. These challenges usually result to losses caused by conflicts, budget overruns, claims and counter claims (Mahamid et al., 2011). The study of Kamanga and Steyn (2013) indicate that, unavailability of construction materials in the construction industry is the direct result of too much claims on construction projects in developing economies which also have effect on construction performance.

According to Choudhry (2012), poor quality, slow progress, lack of cooperation among team members, too much material wastages and tough time in coordinate activities are some of the challenges of NSP method. Doloi et al. (2012) found that, lack of obligation, incompetent site management and poor communication are some of the challenges of shortage of materials on construction projects.

3. RESEARCH METHOD

The method used to conduct the study is the survey research method and the data was collected using a detailed questionnaire. The quantitative technique was used to collect data from respondents. Out of the 90 questionnaires that were sent out to respondents, 67 (giving a response rate of 73%) were retrieved and used for the study. The 67 responses were obtained from randomly selected construction professionals and construction business personnel including: project managers, clients, manufacturers, suppliers, engineers and quantity surveyors. Data obtained through the questionnaire were tabulated and presented using frequency, sum, percentages and mean item score. The Statistical Package for Social Sciences (SPSS) was used to analyse the data collected from the field. Furthermore, the t-test was used to determine the significance of the challenges investigated in the study. Variable were accepted to be significant if their p value is less 0.05.

The mean item score was calculated with:

$$\text{Mean Item Score (MIS)} = \frac{1n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5}{\sum N}$$

Where:
n_1 = Number of respondents for no extent; n_2 = Number of respondents for slight extent
n_3 = Number of respondents for neutral; n_4 = Number of respondents for high extend
n_5 = Number of respondents for very high extent; N = Total number of respondents

4. DATA ANALYSIS

Table 1 indicates the demographic information of respondents. The organisational demography shows that, 14.9% of the respondents were clients, 68.7% were consultants and 16.4% were suppliers/manufacturers. This means that, majority (68.7%) of the respondents for this study were consultants. Consultants normally represent clients' interest on site and hence were satisfactory for this study. Also, 50.7% of the respondents were quantity surveyors, architects, civil engineers and structural engineers (represented with 'others'), 25.4% were project managers, 13.4% were suppliers/manufacturer representatives, 7.5% were directors, and the remaining 6% were procurement managers. Furthermore, 25.4% of the respondents had 11-15 years of work experience, 23.9% had 16-20 years' experience, 20.9% had less than 5 years of experience, 13.4% had 5-10 years of work experience, 10.4% had 21-25 years of work experience and 6% the least were more than 25 years of experience.

In addition, 76.1% of the respondents had Bachelor's degrees, 9 % had post matric, diploma or certificate, 7.5 % had master's degree, 6% had matric certificate and 1.5% had PhD. Also, 52.2% of the respondents had executed between 1-3 construction projects, 26.9% had executed 4-6 projects and 20.9% had executed 7-9 projects respectively. Also, 40.3% of the projects executed were building projects, 38.8% were civil engineering projects 20.9% were building and civil engineering projects. Moreover, 65.7% of the projects were private sector projects while 34.3 % were public sector projects. Lastly, 41.8% of the projects were completed before 2015, 25.4% were completed completed in 2015 and 20.9% completed in 2016. Projects that will be completed in 2017 or later were 1.9%.

Table 1: Demographic information of respondents and their projects

Demographic information	Frequency	Percentage
Organization		
Client	10	14.9
Consultant	46	68.7
Manufacturer/supplier	11	16.4
Total	67	100
Position		
Director	5	7.5
Procurement manager	2	3.0
Project manager	17	25.4
Supplier/manufacturers' representative	7	13.4
Others	34	50.7
Total	67	100
Experience (years)		
0-5	14	20.9
6-10	9	13.4
11-15	17	25.4
16-20	16	23.9
21-25	7	10.4
Above 25	4	6
Total	67	100
Qualification		
Matric certificate	4	6
Bachelor's degree	56	85
Master's degree	5	7.5
Doctorate degree	1	1.5
Total	67	100
Number of projects done		
1-3	35	52.2
4-6	18	26.9
7-9	14	20.9
Total	67	100
Category of projects		
Building project	27	40.3
Civil engineering project	26	38.8
Building and civil project	14	20.9
Total	67	100
Sector of project		
Public sector	23	34.3
Private sector	44	65.7
Total	67	100

Year of completion of projects		
Before 2015	28	41.8
2015	14	20.9
2017	17	25.4
2017 and above	8	11.9
Total	67	100

Table 2 presents the challenges of the nominated supplier procurement method based on the ranking of clients, consultants and manufacturer/supplier. From the clients' perspective, the challenges of nominated suppliers include clash of organizational cultures (4.30), followed by delinquency or deficiency in providing the service required (4.20) and inadequate planning and scheduling by supplier (4.10). Furthermore, the clients rated lack of senior management support in supplier organization (2.80) as the lowest challenge of nominated supplier procurement method.

Table 2: Challenges of nominated supplier procurement method based on organization of respondent

CHALLENGES	**CLIENTS**		**CONSULTANTS**		**SUPPLIERS**		**OVERALL**		
	MIS	**R**	**MIS**	**R**	**MIS**	**R**	**MIS**	**R**	**SIG**
Inadequate planning and scheduling by the supplier	4.10	3	3.83	4	4.09	1	3.91	1	0.703
Fluctuation of prices associated with the prevailing supply–demand cycle	3.60	8	3.93	3	3.91	3	3.88	2	0.771
Lack of commitment by the material supplier	3.30	10	4.00	2	3.91	3	3.88	2	0.234
Suppliers' non-adherence to the condition of the contract	4.10	3	3.78	5	3.82	4	3.84	3	0.786
Lack of belief in the supplier system by the client and the contractor	3.90	5	3.76	6	3.55	7	3.74	4	0.826
Shortage of foreign currency for importation of materials	4.20	2	3.63	9	3.73	5	3.73	5	0.453
Changes in materials types and specifications during construction	3.70	7	4.02	1	2.55	13	3.73	5	**0.004**
Lack of trust among the team members	3.80	6	3.63	9	4.00	2	3.72	6	0.745
Increase in material cost	3.70	7	3.65	8	4.00	2	3.72	6	0.647
Clients interference with suppliers	3.20	11	3.78	5	3.73	5	3.69	7	0.438
Clash of the organizational cultures	4.30	1	3.61	10	3.45	8	3.69	7	0.273
Delays in Materials delivery to the construction site	3.40	9	3.72	7	3.64	6	3.66	8	0.755
Mistakes during the construction and delivery of stage/phase materials	4.00	4	3.50	12	3.91	3	3.64	9	0.467
Suppliers financials problems	4.10	3	3.50	12	3.82	4	3.64	9	0.354
Poor quality of materials supplied or delivered to site	3.90	5	3.65	8	3.36	9	3.64	9	0.649
Clash among suppliers, clients and contractors	3.40	9	3.61	10	3.82	4	3.61	10	0.794
Lack of communication between parties	4.00	4	3.50	12	3.64	6	3.60	11	0.621
Unchanging attitudes of suppliers	3.10	12	3.61	10	3.82	4	3.57	12	0.521
Lack of senior management support in clients' organization	4.00	4	3.39	15	3.73	5	3.54	13	0.497

Lack of co-operation among the construction members and suppliers	3.70	7	3.52	11	3.27	10	3.51	14	0.747

Table 2 Cont'd

Supplier delivered less quantity of materials to site	3.80	6	3.48	13	3.27	10	3.49	15	0.673
Previous disputes not resolved	3.10	12	3.41	14	4.09	1	3.48	16	0.247
Damage of sorted materials while they were needed urgently	3.20	11	3.48	13	3.73	5	3.48	16	0.660
Lack of appreciation for contractual risk by suppliers	4.00	4	3.35	16	3.45	8	3.46	17	0.420
Late procurement of construction materials by suppliers and contractors	3.70	7	3.22	17	3.55	7	3.34	18	0.508
Delinquency or deficiency in providing the service required	4.20	2	3.07	19	3.36	9	3.28	19	0.061
Skilled shortage in material supplier sector	2.80	13	3.41	14	3.09	11	3.27	20	0.463
Shortage of construction materials in market	3.30	10	3.17	18	2.73	12	3.12	21	0.292
Delay in manufacturing specialized construction materials	3.60	8	3.07	12	2.55	13	3.06	22	0.266
Lack of senior management support in supplier organization	2.80	13	2.87	21	3.09	11	2.90	23	0.880
1= No Extent 2= Slight Extent 3= Neutral 4= High Extent 5=Very High Extent									

From the consultants' perspective, changes in types of materials and specifications during construction (4.02), lack of commitment by the material supplier (4.00) and fluctuation of prices associated with the prevailing supply–demand cycle (3.98) were ranked as the topmost challenges of the adoption of nominated suppliers' procurement. In the same vein, lack of senior management support was ranked as the least challenge. The consultants rated inadequate planning and scheduling by the supplier (4.09), increase in material cost (4.00), and fluctuation of prices associated with the prevailing supply–demand cycle (3.91) as the highest challenges of nominated supplier procurement method. While the challenges of nominated supplier procurement method vary among the client, consultant and suppliers, t=test show that the only challenge that is significant among the threeset of respondents was changes in materials types and specifications during construction.

5. DISCUSSION OF FINDINGS

The findings revealed that the top 5 challenges of nominated supplier procurement method are inadequate planning and scheduling by the supplier, fluctuation of prices associated with the prevailing supply–demand cycle, lack of commitment by material suppliers, suppliers' non-adherence to condition of the contract, lack of belief in the suppliers' system by the client and the contractor and shortage of foreign currency for importation of materials.

These findings are somewhat similar to the findings of Trauner (2009) who noted that, delays caused by materials are as a result of: unavailability of construction materials in the market, modification in the type of materials and specifications during construction, delay or late delivery of materials, damage of arranged materials while they are needed immediately, delay in manufacturing superior building materials and late attainment of materials. Furthermore, the results are similar to that of Jarkas and Haupt (2015) who found that, unavailability or shortage of construction materials, lack of proper planning and procurement management on the contractors' part and suppliers' deficiency in providing the services required, instability of prices related to the supply–demand cycle are challenges of nominated supplier procurement.

6. CONCLUSION

This research investigates the challenges of nominated supplier procurement method in the construction industry. The rating of the challenges according to the respondents shows that there are many challenges militating against the adoption of nominated supplier procurement method. These changes are different from stakeholder to stakeholder, depending on the person involved. Despite the enormity of these challenges however, the research concludes based on significance test done with t-test. Hence, the conclusion of the study is that, though there are many challenges militating against the success of nominated supplier procurement method, changes in types and specification of materials during construction is the only challenge that is significant to the client, consultants and manufacturers/suppliers.

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Preparing Construction Contractors for Post-Disaster Recovery Operations

Bassam Baroudi
The University of Adelaide, South Australia, Australia
sam.baroudi@adelaide.edu.au

Randy Rapp
Purdue University, West Lafayette, Indiana, USA
rrapp@purdue.edu

Abstract
In the aftermath of a disaster there is a need for conventional and specialist contractors to perform immediate mitigation and rectification of hazardous situations followed by expeditious restoration and reconstruction of the built environment. The question is what can they do to prepare their companies for service both to themselves and to the affected community? This area of disaster reconstruction project management is quite complex and presents unique challenges in respect to the availability of skilled personnel, materials, equipment and supporting infrastructure. Hence, a special type of planning is required for contractors to be appropriately prepared so that they can serve the disaster affected community. This paper presents a review on disaster management and reconstruction research and literature. It follows on to provide a commentary on the subject and how contractors can better prepare their organisations for disaster events. The study is important as disaster preparedness is quite often taken from that of a first responder, community or government perspective but rarely from that of the contractor. Hence, further thinking is required to offer a more strategic view in respect to disaster preparedness and gearing contractor operations to be agile enough to cope with the influx of such projects. The benefit to disaster affected people, the built environment and indeed the contractors themselves could be measurably significant.

Keywords
Disaster Preparedness, Reconstruction, Contractor Planning

1. Introduction

Disaster events create situations outside of the norm causing disruption to people, communities and business. It is held by many that disasters are occurring more often with this increase creating a real problem for those living in populated urbanised areas (Asian Disaster Reduction Centre 2012, Abkowitz and Chatterjee 2012, Guha-Sapir et al. 2014, Mitchell et. al. 2014, Ingirige 2016). Once a disaster strikes there is an immediate need for first responders to attend to medical emergencies and immediate community needs. Following this comes the task of restoring and reconstructing the built environment to its original (or better) condition. As such, it is for contractors to prepare their companies in readiness for disaster events so that they can serve the affected community and benefit their business operations.

Walker et al (2017) contend that reconstruction projects are quite different to standard construction projects having to compress the required recovery works into a very short time period. It is this heightened level of expectation that contributes to making disaster recovery projects quite challenging. Sun and Xu's (2011) investigation of the 2008 Wenchuan Earthquake and reconstruction also points to reconstruction time and the critical importance that is placed on this factor within post disaster recovery operations. They also go on to describe 'post-earthquake reconstruction project management' as an area which concerns a multiple project management approach which requires the ability to act quickly and flexibly to deliver required outcomes.

This study aims to look at disaster restoration and reconstruction preparedness from the contractor standpoint and the challenges that they face in this respect. This is as opposed to a first responder perspective which is quite typically what many focus on when addressing these events. A literature review that outlines some current thinking in respect to disaster events and preparedness, and organisational planning and project implementation will be presented. This will be followed by a commentary from the authors who have combined experiential and research backgrounds within disaster management, construction and project management. It will particularly look at contractor perspectives of disaster preparedness via the lens of strategic organisational and operational planning so that project objectives have the best chance of success. It is expected to contribute knowledge to the project and construction management disciplines within the disaster recovery context.

2. Disaster Events and Stakeholders

General disaster events and catastrophes create dire circumstances that society is more often than not ill equipped to handle. Opdyke et al. (2017) contend that disasters impact social, economic and infrastructure systems having real consequences for many stakeholders such as affected communities, governments and various organisations. Comfort (2005) adds that extreme events such as disasters highlight a cascading effect of failures due to independencies within our societal systems in affect causing disruption to everyday life. As such, it would seem important that sensible disaster recovery planning that serves individuals, organisations and the broader community is undertaken.

Eid and El-adaway (2017) believe that for success to be achieved in disaster recovery operations a wide array of stakeholders need to be actively engaged during the planning stage and throughout the implementation or execution of work activities. Essentially the process requires broad involvement with those potentially affected. Chan and Oppong (2017) contend that in any project situation it is important to meet stakeholder expectations. They put forth that on construction projects engaging stakeholders and having them participate is an effective way of ensuring that their varying and diverse expectations are met. Within the disaster context it perhaps becomes more crucial to engage with stakeholders at a deeper level and look more broadly at those affected and how satisfactory outcomes can be achieved. This is challenging with severe resource shortages and poor work environments typical of post disaster scenarios.

It would seem imperative that stakeholders such as government agencies, insurance companies, businesses or individuals engage appropriate contractors for disaster recovery projects. San Cristóbal (2012) contend that selecting the right contractor for projects is critical and that the client needs to be confident that the contractor can deliver as required. It is put forth that this is one of the biggest challenges within what could said to be business-as-usual environments. This situation would be significantly magnified when a region is in post disaster disorder and demand for contractors is at a high level. Furthermore, in these instances the 'right' contractor would not only be qualified both technically and commercially, but would also be able to demonstrate empathy towards victims. Preplanning the selection process or adopting some form of contractor register may be of benefit to both client and contractor preparedness should disaster strike.

3. Contractor Organisational Planning

Hwang et al (2007) inform that disasters create a situation of facility dysfunction and disruption to everyday activities creating a loss of work continuity and potentially business failure. This creates a risk to contractors, suppliers and the community at large. Those charged with organisational planning need to consider disaster driven disruption and how operations and resourcing can be maintained in situations of recovery. In respect to project resourcing Chang et al. (2010) put forth that there are huge problems in this area in the post-disaster recovery phase. They say that the construction marketplace can be in complete disorder with supply chains cut or disrupted throughout the region due to damaged facilities and general infrastructure. Perhaps the worst result is the loss of electrical power for many days or weeks as this impacts almost every business function. For example, credit systems may not function, so much so that cash and a means to secure it are often required. Hence, contractors need to look closely at their organisations and think about the possible occurrence of extreme events and how they can sustain business continuity and serve the affected community.

The issue of contingency planning is at the forefront for disaster recovery operations in the built environment. Thomas (2010) discusses contingency situations as related to incidents such as disasters in a military sense which is of value to this inquiry. He says that contingency construction has three broad classifications of temporary, expeditionary and permanent. These classifications provide a range of construction type deliverables that span from three months to one year for temporary and expeditionary with permanent being the final finished deliverable. Construction contractor planning may need to consider the possible need of supporting facilities for humanitarian relief alongside the more long term objectives, i.e. to maintain life and implement recovery actions to bring back semblance of normalcy to full pre-disaster conditions.

Kim and Choi's (2013) research on flood disasters discussed a need for clear 'post-disaster rebuild methodology'. They highlighted that recognised processes and techniques as offered by the project management discipline can assist in post disaster recovery reconstruction situations. They discussed it more from an overarching client view but similar actions could be taken by contractors when thinking about reconstruction activities. Contractors could benefit by integrating such methodologies into their overall organisational planning initiatives. Furthermore, Hwang (2016) see the necessity to seek improvement within construction processes so that time, cost and resource constraints are addressed and they see it particularly so in construction operations of a complex and uncertain nature. In a post disaster reconstruction this would certainly be the case which further underlines the need for contractors to prepare their organisations in readiness for such situations.

4. Project Operational Preparedness

Considered organisational planning is important providing a foundation for operational solutions to post disaster problems at the project level. The appointment of qualified project and construction managers is important for successful disaster recovery operations. At the forefront is that they must be standout leaders and as Toor and Ofori (2009) point out effective leadership is required to succeed when confronted with the many challenges that come with construction projects. Strength of leadership is particularly required in difficult environments such as that offered by post disaster events. Furthermore, Rapp and Baroudi's (2014) research found that in the disaster recovery context leadership traits and core values such as communication skills, personal integrity and compassion were identified as of high importance. When planning for disaster reconstruction projects contractors may need to consider the more unique qualities required and designate project personnel accordingly.

The Christchurch earthquake disasters of 2010 and 2011 can offer something on how to lead disaster recovery reconstruction teams. Walker et al (2017) discuss the Stronger Christchurch Infrastructure Rebuild Team (SCIRT) who were charged with undertaking the disaster recovery operations including the reconstruction and repair works as required. This was based around creating an alliance of construction companies. Five companies were chosen and each used their own employees and subcontractors on the various reconstruction projects. The companies assembled delivery teams with individual project directors and delivery leaders and these people managed the connection between the various parties from planning and design through to the reconstruction activities. Orabi et al (2010) can also contribute within the area of project resourcing. They developed a resource utilisation model so as to distribute competing resources during post disaster recovery operations. This model could possibly assist project leaders of reconstruction projects with a resource planning approach in preparedness for a disaster event. The model is based around three levels of allocation. First to look at the contractor level, followed by the project level and then to focus in on the activity level. By splitting the process into three levels it makes it easier to approach the problems associated with reconstruction and frontline resourcing.

To look at project operations and the planning for preparedness thereof in the broader context Ingirige (2016) offers insight in respect to selfless actions and working towards a common goal. He suggests that key people in the supply chain system that provide reconstruction project requirements should go beyond self-interest and break free from a silo driven inward view to one which is more outward so as to build a more resilient approach to disruptive events and improve project outcomes. This infers that preparation for disaster events at the project level should include an open exchange between contractors, subcontractors and suppliers, with the outcome outlining potential disaster recovery involvement and subsequent behaviours.

5. Commentary: Contractor Disaster Preparedness

Disaster events create disorder within our social systems unlike any other occurrence. They destroy life and property and generally raze the natural and built environment. However, humankind is yet to come to terms on how to prepare and plan for such events and in fact are still on a learning trajectory which would currently seem in its infancy. Disasters are increasingly discussed in many discipline areas including health, transport, architecture and building, the environment, engineering, IT and social sciences. This is because disasters are non-discriminatory and impact on many parts of society. In turn this creates many disaster affected stakeholders as Opdyke et al. (2017) and others have expressed. Academics and practitioners alike are constantly adding new knowledge in an attempt to progress society in respect to dealing with disaster events so that ad-hoc retrospective actions are replaced with resilient ready-to-go plans. One area that appears to be lacking in knowledge and requiring more attention is the contractor viewpoint in respect to post disaster operations. Hence, this commentary will focus on the construction sector and contractor preparedness and planning as needed in post disaster situations to expeditiously reinstate the built environment back to a habitable condition.

Contractor organisations in their normal course of business take on building and infrastructure projects within their scope of capability and as suits their company objectives. They must deal with internal and external stakeholders on an ongoing basis to manage and deliver client requirements. However, when it comes to a post disaster situation the business-as-usual assumptions that one might make cannot be relied upon. For example, organisational functionality, resource bases, operating supply chains, location accessibility and infrastructure requirements are just some items that have been highlighted by many in the generic sense. These areas become problematic for contractors, suppliers and associated businesses and hinder efficient disaster recovery operations. Hence, it is deemed necessary that organisational and project requirements require significant operational planning in preparedness for what a post disaster landscape may hold for contractors. The area requires both experienced personnel and innovators to contribute to the conversation. In essence, it requires deep thinking and strategic intentions to ensure that the assumptions made in everyday situations are viewed in terms of greater uncertainty and complexity with increased personal and business risk inherent in the decision-making.

Common experience tells us that speed and thoroughness of sufficient analysis of an operational planning problem can be improved with a routine format and content for consideration of relevant factors. The success of highly contingent operations such as those post disaster depend on more thorough planning than routine operations require. Perhaps no organisations routinely plan to deal with contingent operations of greater scope and impact than the military such as discussed by Thomas (2010). Outcomes of their efforts can change lives especially during the response phase but even the recovery phase operations can result in stark changes for the economic and social trajectories of affected citizens, local communities and regions. Analysis that weighs such conclusive possibilities is appropriate for response to major natural or man-made disasters, since lives can also be at risk for such events. The operational planning format applied by military organisations of many nations thus merits consideration; modified to suit unique needs of construction contracting organisations. A mere format, no matter how long used or proven, does not necessarily equate to a good plan of action. However, the planning process that it guides is certainly a major step to a good plan. Furthermore, the format lends itself to assignment of related tasks to responsible personnel within functional areas. No operational plan has much value unless it focuses on action. Applying that operational planning format to the contractor organisation will provide guidelines on how the entity is expected to perform in post disaster situations.

It is deemed that having an operational plan for post disaster preparedness is of importance. However, it would seem that it is not a concept that many contractor organisations give much attention. In between, the daily efforts of running the contractor business, winning new work and maintaining project progress and profitability there is a time deficit that not many organisations can overcome. However, if post disaster operational planning can be integrated into everyday organisational functions perhaps there is a chance of addressing the issue. For example, company directors can produce a policy document in addition to their general policies, certain employees can be designated time to implement policies and develop plans and general personnel can be kept up to date during normally scheduled meetings. During these meetings contractor staff can be informed on how the company will seek to operate during and after post disaster events. Of course the plans will need to consider issues regarding existing project operations and associated project safety, resourcing, schedules, costs and quality. So a documented operational plan should display some form of resilience in organisational and project terms. For example, what are the lines of responsibility and who are the operationally essential people in this respect and can a typical action list be formatted to assist. Furthermore, disaster recovery project communications require serious consideration. In this day and age communication can be made via various devices and mediums. However, when disaster strikes many if not all of these may become disabled. This could particularly impact remedial and mitigation works in the first instance. Of note is post Hurricane Katrina both cellular communication and electrical power were compromised for nearly a week in some areas with costly fossil fuel generators powering satellite phones and internet saving the day for many organisations. As such, the operational plan should include how the work is to proceed until normal communications are restored. It should also list various emergency contact details so that appropriate agencies, contractor personnel, subcontractors, suppliers etc. can be reached in a time of crisis.

An important point to make is that the operational plan needs to address existing projects first then seek to venture into the approach of acquiring new projects – disaster reconstruction projects. It is analogous to stabilising the ship then trying to sail forward. There will be an abundance of reasons why post disaster reconstruction projects will be difficult to manage and deliver. However, planning needs to look at innovative ways of addressing constraining issues. The study has already raised possible reconstruction project constraints such as availability of resources and broken supply chains. However, reconstruction contractors and project managers need to forecast further out in respect to what they see as disaster imposed constraints as applicable to their region. This could be possible infrastructure scenarios learned from past disaster events (e.g. flooding of roads), or any safety aspects including special job hazards, or the difficulty of acquiring project staff. The aspect of acquiring qualified staff that can work long hours, in extreme and fairly primitive environments for many weeks or months on end could be particularly challenging. Of course time constraints as mentioned by Walker et al (2017) and Sun and Xu's (2011) will further compound most other project constraints. So planning for the logistical requirements will be uncertain and possibly difficult but having a set of documented actions in place is perhaps better than having none.

It has been put forth that a judicious operational plan with adequately format processes and procedures for carrying out disaster recovery reconstruction projects as well as maintaining continuity of existing projects is needed. Contractors and their site managers should work at organisation and project levels to seek solutions to multidimensional problems as can be forecasted. This perhaps summons a need to look outwards and seek answers outside of normal business-as-usual conditions. For example, preparing by investigating potential business/financial partners, project staff, subcontractors and suppliers from possibly unaffected regions unconstrained by catastrophe and stating how these could be operationalised within documented plans could help. At least contractors would be in a more assured position should a disaster situation present itself with possible prior written agreements such as memorandums of understanding between parties where assets in unaffected regions can move to the assistance of those in the disaster zone. Such a move may even blossom into beneficial relationships whether a disaster event occurs or not. This is essentially about the contractor organisation planning for a form of agility to move quickly and efficiently with specified reconstruction project delivery options. Moreover, planning is important but so is rehearsing the plan as time and money permits. In this context, one can only hope that forward thinking public agencies provide funds for periodic involvement of private sector entities whose capabilities will be useful to the post-disaster public well-being.

To broaden the discussion one step further, another aspect of disaster recovery projects is for contractor planning to go beyond borders and seek opportunities in disaster affected regions that may be accessible to the organisation. This would be more the case if the contractor's region has not been affected by disaster. In this way the unaffected contractor organisation can work from a home base with subcontractors and supply chains relatively intact and assist the disaster affected community in a more stable and controlled manner. National firms would be well placed in respect to this initiative. Contractors could send staff, subcontractors and workers to affected areas on a rotating basis to reconstruct affected buildings and facilities. Of course, part of the planning would need to investigate general business, building licencing and statutory requirements of neighbouring regions.

6. Conclusion

This paper set out to investigate how construction contractors can best prepare for post disaster events via the use of strategic operational planning. It is surmised that maintaining contractor business continuity whilst seeking reconstruction opportunities in disaster affected environments is challenging. Hence, broad informed discussion is needed in the development of disaster recovery operational plans. The plans should include strategic intent on aspects such as organisational positioning, leadership structures, project resourcing, communication channels and much more. This will facilitate for better outcomes for business, projects and affected communities.

There will always be the naysayers who claim that disasters are rare so why go through all the time consuming planning. However, adequate preparations would serve the contractor and community well and the disaster itself does not have to be at the catastrophic level for the planning activities to be of valuable use. The benefits of contractor planning include stabilising the contractor's business and current operations, delivering on pre disaster contracts, taking on reconstruction projects in their region and also further away in disaster affected regions in cases where their region has possibly not been unaffected. It's about being flexible and having a plan that creates a ready-to-go mantra. Furthermore, such contingency planning can lead to improvements in routine operations by a compellingly close look at assets and their employment, personnel capabilities, and the innovative melding of their performance characteristics. At another level, planning for disaster events is important so as to reduce hardship and stress for affected people and notably aspects such as compassion, personal integrity and selfless actions as mentioned by Rapp and Baroudi (2014) and Ingirige (2016) should be promoted from the outset.

In conclusion, effective strategies that encourage ongoing development via lessons learned in respect to disaster recovery operations will produce maturity within operational plans and ultimately lead to continuous improvement. This will in turn benefit contractor businesses and organisational and project preparedness providing a greater service to disaster affected communities. It is intended that future empirical research will investigate the current situation in respect to contractor viewpoints on disaster recovery preparedness and report the results in the form of evidence based findings.

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Overview of Accelerated Bridge Construction Techniques in Highway Bridge Construction in the United States

Amin K. Akhnoukh
Associate Professor, East Carolina University, Greenville, North Carolina, USA
Akhnoukha17@ecu.edu

Tarik A. Youssef
Assistant Professor, French University in Egypt, Shorouk City, Cairo, Egypt
Tarik.youssef@ufe.edu.eg

Chao "Luna" Xiao
Associate Professor, East Carolina University, Greenville, North Carolina, USA
Xiaoch17@ecu.edu

Abstract
The National Bridge Inventory (NBI) of the United States includes more than 600,000 highway bridges with spans exceeding 20 ft. Approximately one-fourth of the nation's inventory are structurally deficient or functionally obsolete, thus, repair, rehabilitation, or total replacement is required to maintain the highway bridges from collapse.

The total cost of required bridge maintenance activities requires a total annual budget of $15 billion compared to a $1 billion available budget at the Federal Highway Administration. The budget deficiency requires innovative techniques in bridge rehabilitation and replacement that provides the construction industry with sufficient savings in the direct and indirect cost of bridge maintenance activities. Accelerated Bridge Construction (ABC) techniques are introduced as a new-approach that uses innovative planning, design, and construction techniques in a cost-effective manner to reduce the onsite activities, utilize site-available topography and materials to reduce construction time and consumed materials, and minimize the use of heavy equipment. Recent studies by the Federal Highway Administration proved that ABC techniques has resulted in minimized detour time, and significantly reduced the overall bridge construction projects by months to years.

Keywords
Accelerated Bridge Construction (ABC), Structurally Deficient, Maintenance Activities, Detours

1. Introduction

The National Bridge Inventory of the United States includes more than 600,000 highway bridges with spans exceeding 20 ft. Approximately 12% of the bridge inventory is structurally deficient, which

needs immediate partial repair to bridge load-bearing members, and 14% of the bridges are functionally obsolete with improper alignment, small-sized lanes, unsafe approach inclination, or geometrical problems that result in increased accidents and/or traffic delays.
The 2017 Infrastructure Report Card published by the American Society of Civil Engineers (ASCE Report Card, 2017) shows that almost 4 in every 10 bridges in the United States are 50 years or older, and on average there are 188 million trips over a structural deficient bridge. The average age of bridges within the NBI is increasing resulting in a higher risk to the safety of commuters. The current overall rating of the bridge network is C+, which indicates that the infrastructure included in this network is in a fair condition with a general sign of deterioration. A recent study by the Federal Highway Administration (FHWA) stated that a budget of $15 billion is required annually to improve the bridge conditions versus a budget of $1 billion currently available at the FHWA. The budget deficiency requires different innovative approaches to the maintenance, repair, and replacement activities required to maintain or restore the deficient bridges. Among the possible approaches, the use of Bridge Management Systems as a tool to define the different problems, and prioritize the required maintenance activities (Akhnoukh and Morcous, 2005). To-date, the FHWA and Different State Departments of Transportation are adopting a new approach for bridge maintenance, repair, and replacement known as *Accelerated Bridge Construction* (ABC). ABC is defined as bridge construction that uses innovative planning, innovative design techniques, on-site materials, and construction methods in a safe and cost-effective manner to build new bridges and maintain, repair, or replace existing ones (Adams et al., 2012). The innovative ABC approach in planning, construction methods, and materials selection results in the construction of durable bridges with longer life spans at a reduced cost.

This paper presents different ABC technologies adopted by different State DoTs, the optimum site conditions and project constraints associated with each technology, and the attained advantages for adopting ABC technology in various bridge construction project. A Case study is presented to explain how the incorporation of ABC technologies and high strength construction materials result in material and labor savings.

2. Accelerated Bridge Construction (ABC) Technologies

Three different ABC technologies are currently adopted and promoted by the FHWA and State DoTs in various bridge construction and maintenance projects. These technologies are *1) Prefabricated Bridge Elements and Systems (PBES), 2) Slide-In Bridge Construction, and 3) Geosynthetic Reinforced Soil – Integrated Bridge System (GRS-IBS).* The implementation of each technology depends on specific project objectives, construction site topography, geotechnical conditions, type of the construction bridge and its intended use.

2.1. Prefabricated Bridge Elements and Systems (PBES)

Prefabricated bridge elements and systems is one of the main ABC strategies adopted in the construction of new bridges or the replacement of deteriorated elements of aging bridges. PBES are structural components that are fabricated off site and moved for the construction site for direct installations. PBES includes features that allow fast construction and are mainly fabricated using high performance materials for increased strength and better long-term performance of the constructed or repaired bridge. The fabrication of bridge elements off site enables the project contractors to operate in a controlled condition which improves the quality of the PBES, reduces construction time, and improves the overall safety of the project. PBES includes the following elements and systems:

- ***Deck elements*** that are fabricated off-site and transferred for direct erection, which eliminate activities associated with conventional deck construction including falsework, formwork, reinforcing steel placement, concrete pouring and curing, and formwork removal. Examples of deck elements include prefabricated deck panels, lightweight precast panels, and FRP deck panels, and fiber-reinforced polymer honeycomb “lightweight” panels.

- ***Girder elements*** including AASHTO girders, NU girder (Akhnoukh, 2008), bulb tee girders, and adjacent box girder. Girder elements fabricated for PBES are poured and cured off site using advanced curing methods, which results in high early strength of concrete, and lower permeability due to higher consolidation.
- ***Pier elem*****ents** that eliminates the time required for formwork, reinforcement placement, concrete pouring and curing. Pier elements include prefabricated caissons, pier caps, prefabricated footings and columns.

The afore-mentioned precast/prefabricated elements could be used in attaining a significant reduction in scheduled activities duration and minimizing the amount of critical activities within the construction project duration. In addition to prefabricated elements, prefabricated systems can be used as an ABC techniques to minimize or eliminate the use of temporary alignments or temporary bridge structures. Examples of prefabricated systems include full-width beam span with deck and girder-deck Pi-girder developed by researchers at the Massachusetts Institute of Technology (Keierleber et al., 2007). The MIT Pi-girder is shown in Figure 1.

Figure 1: MIT 2nd Generation (FHWA Report, 2009)

2.2. Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS)

The Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS) is an innovative approach that allows bridge contractors to execute their bridge construction project in a short construction period due to the use of on-site materials in bridge construction. The GRS-IBS approach depends on using layers of compacted granular fill, naturally available at construction site, alternatively with geosynthetic reinforcement that provides a stable seamless approach to the bridge span. The simple earth work results in a cost reduction up to 50% as compared to bridges constructed using conventional method.

The GRS-IBS bridges are durable due to the few man-made materials used in its construction. Aside of bridge durability, the required maintenance is minimal which results in fewer traffic disruption and lower life-cycle cost. The GRS-IBS construction technique provides the bridge with a seamless approach as it eliminates the bump at the bridge due to alignment issues at construction. The elimination of approach bump decreases the dynamic loads due to vehicle impact, which reduces the structure and vehicle maintenance. Additionally, elimination of approach bump eliminates the accidents occurring due to the driver loss of control, hence, improve the serviceability of the bridge. Typical GRS-IBS bridges are short one-span bridges that does not exceed 150 ft. in length and are constructed in a shallow terrain with a total depth that does not exceed 30 ft. as shown in Figure 2.

Figure 2: One Span GRS-IBS Bridge (FHWA, 2017)

2.3. Slide-In Bridge Construction (SIBC)

Slide-In Bridge Construction (SIBC) is one of the main ABC techniques adopted by the Federal Highway Administration to provide bridge constructors with a cost-effective tool to replace an existing bridge without impacting the traffic mobility or safety at the bridge construction location. Currently, the state highway agencies are working with the FHWA to develop their SIBC implementation guides and construction manuals through Every Day Counts initiative. The main objective of the FHWA collaboration with state agencies is to provide standard specifications to the SIBC technology and adopt SIBC technique as a part of the standard practices in bridge construction.

SIBC allows for the prefabrication of a new bridge at a precast facility or on-site using temporary supports adjacent to the aging bridge. Once the bridge construction is completed, a short-period full-traffic shut down is implemented to demolish the aging bridge and slide in the new bridge to occupy the same place before traffic restoration, as shown in Figure 3.

Figure 3: SIBC Construction Project by Washington State DoT (FHWA, 2017)

3. Accelerated Bridge Construction Current State of Practice

The implementation of ABC innovative approach has been increasingly incorporated in different bridge construction projects in the United States in the recent years to maintain and improve the US bridge network conditions given the FHWA budget deficit. Since 2010, 8 bridges were constructed using the *GRS-IBS* system. Current research is focused on the advantages of using short span metal and concrete arch bridges in rapid construction of GRS-IBS system bridges, with major emphasis on stream-crossing and railroad bridges. Similarly, more than 800 bridges have been designed or constructed using *PBES* system. Multiple research projects are currently investigating the potential of using ultra-high-performance concrete, high strength concrete, and larger prestress strands in the prefabrication of bridge girders with superior mechanical properties (Akhnoukh, 2010). In a relevant study, high strength concrete (compressive strength of 15 ksi) and larger 0.7 inch. Prestress strands were successfully used to design a 105 ft girder bridge panel with a 4 NU900 girders spaced at 12 ft. instead of a 6 NU900 girders spaced at 8.0 ft. for the same loading condition. The alternative design, shown in Figure 4, using high strength concrete and larger prestress strands resulted in a direct material saving of 14%. The use of fewer girders result in a lighter superstructure, shorter construction schedule, labor and equipment savings.

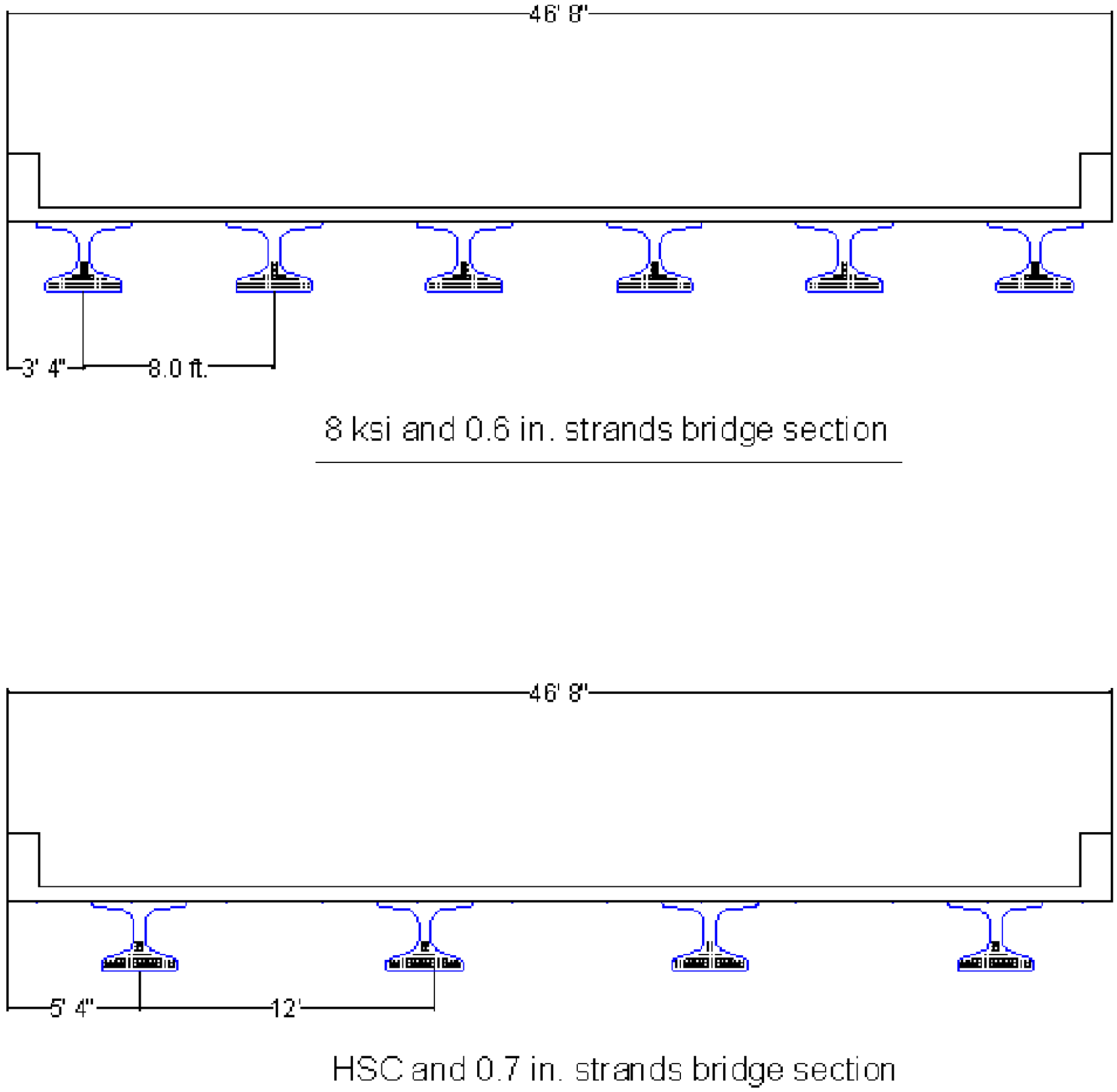

Figure 4: Superstructure Savings Using HSC and 0.7 Inch Prestress Strands (Akhnoukh, 2008)

4. Benefits of Different ABC Techniques

The overall benefits of ABC techniques include *reduced construction cost, reduced traffic interruption periods, higher quality control for bridge construction due to the fabrication of bridge elements on a controlled off-site environment, more durable bridges with lower life-cycle cost compared to conventionally constructed bridges, higher job site safety, and reduced impact on the surrounding environment*. The afore-mentioned advantages are generally associated with accelerated bridge construction. However, specific advantages are attributed to the specific bridge technique adopted by the bridge constructor. Specific advantages relevant to different ABC techniques are shown in Table 1.

Table 1: Specific Benefits of Different ABC Techniques

	GRS-IBS	PBES	SIBC	Remarks
Reduced Construction Cost	X	X	X	Shorter construction duration, reduced site conflicts, and minimized traffic interruption results in reduced project budget
Shorter Construction Schedule	X	X	X	Minimized on-site activities reduces construction time
Durable – Longer Bridge Life Span	X	X	X	Better quality control due to off-site construction
Reduced Environmental Impact	X	X	X	Minimized detours and minimized rerouting and stream mitigation activities
Eliminated Approach Bump	X			Integrated approach-deck construction using geo-synthetic fibers eliminates approach bump
Possible On-Site Changes		X		Possible activity and schedule changes due to limited critical activities (for off-site construction)
Easier Utility Installation		X	X	Utilities are fabricated off-site and inserted/tied after it is relocated to the construction site
Lower Life-Cycle Cost	X	X	X	Improved quality control results in a better construction and minimized maintenance activities

5. Summary and Conclusions

The Accelerated Bridge Construction Technique (ABC) is currently researched by the Federal Highway Administration and Different State Departments of Transportation as an innovative approach for new bridge construction and maintenance, repair, and replacement of aging bridges with noticeable deterioration. According to research findings, the main ABC technologies *Prefabricated Bridge Elements and Systems (PBES), Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS), and Slide-In Bridge Construction (SIBC)* are providing bridge owners and contractors with successful techniques for rapid construction with better quality control, higher job site safety while reducing the traffic interruption and minimizing the labor and construction equipment utilized during the project duration. In order to maximize the benefits of ABC approach, high strength construction material, innovative bridge systems are to be incorporated. Based on attained advantages, the Federal Highway Administration is currently working with state agencies to adopt ABC techniques as a standard way of executing bridge construction projects.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

Global Construction 2030 Market at Top Three Nations

Roberto Soares, PhD, DSc, MBA,AIC,DBIA, PE
Teaching Assistant Professor, East Carolina University, Greenville, NC, USA

Amin K. Akhnoukh
Associate Professor, East Carolina University, Greenville, North Carolina, USA
Akhnoukha17@ecu.edu

Abstract
The Global construction market is showing an increase in the needs of construction services over the years, it is forecasted that by 2030 the global construction market will be worth $ 17.5 Trillion. Data from the Global Construction Report 2030 indicates that China, US, India will account for 57% of the total market worth value. The aim of this paper is to analyses the environment, the business opportunities and the objectives of these three countries using strategic management technics as: PESTLE, SWOT, and SMART to provide convincing arguments for construction enterprises interested in service these countries. Dedicated analysis and recommendations for each country listed above will be provided.

Keywords
Global Construction, PESTLE. SWOT, SMART, Business Opportunities.

1. Introduction

Multinational construction organizations organize themselves to provide services and products under a global perspective of changing the landscaping of several economies with their participation in Engineering and Construction projects, enjoying the monetary benefits associated with these projects. The ENR Top 250 Global Contractors had $ 501.14 billion in revenues in 2016 from projects outside their home countries, which represents 36% of their total revenues.
Global construction projects demand a more complex risk analysis study due the need to understand the impacts related with cultural issues, language barriers, religion influence, ethical standards, legal issues, compatibility of international engineering and construction standards, global environmental issues, inflation, construction material availability, lack of specialized labor, availability of heavy equipment, import/export policies, monetary policies to repatriate profits, and global terrorism issues.
The size of the Global construction in 2030 forecasted by Oxford Economics (2016) is $17.5 Trillion, which is an increase of $5.5 Trillion in the last 10 years (Ochieng et all,2013). China, US, India, will be responsible to generate most of the investment of the total market worth value. To develop a scenario of the three Nations listed above, the PESTLE (Political, Economic, Social, Technological, Environmental factors), SWOT (Strength, Weakness, Opportunities and Treats factors), and SMART (Clear, Specific, Measurable, Achievable, Realistic, and Time factors) tools is used to evaluate the environment and the business opportunities. A discussion Economic, Social, Technological, Environmental factors) of the finds will be

provided, as well as recommendations, focusing the business opportunities at the global construction 2030 market.

2.0 China

2.1 Environment (PESTLE Analysis)

Political: Their Government sets formal and informal rules that firms must abide by. Their Government has taken interest in the development of e-commerce. The legal firm work for e-commerce is still in its infancy. Economic: China's GDP has grown over the past five years, forecasted to pass U.S. GDP in the coming years ahead. Factors that contribute this are; Sigh rate of savings, abundant and skilled labor, more export business and potential urban growth. Social: The reversal of the One-Child Policy will support long-term growth. Family size and social behavior will impact how financial decisions are made. Technological: China does not have a safe and reliable online transaction system. Hints their Governments interest in development of e-commerce. Also, there has only been a one percent (1%) growth in credit card penetration in that country. Legislative: China is aggressively formulating legislation to accommodate the development of e-commerce. Environmental: With their populations heavy usage of e-commerce, this will decrease air pollutants created using vehicle emissions (PESTLE, 2016a)

2.2 Business Opportunities (SWOT Analysis)

Strength: Accelerated economic development will continue to dominate light and medium-tech industries because of the large market in China and pool of labor. Will be one of the world's six (6) largest economies by 2020 with Japan, Indonesia, India, and Korea and the U.S., according to the World Bank. Weaknesses: Some disorder in the financial sector. Wage growth has not kept pace with inflation. Roads are jammed with thousands of bicycles, buses, trucks, and taxis. Average schooling term nationwide is only six (6) years. Opportunities: Demand for foreign loans to construct more than 30,000 km of rail lines and to build expressways and classed roads. Need for overseas investment in coastal ports since more than 90% of exports are carried by sea. Threats: Rapid internal changes in Chinese society. Must hire Chinese managers to better understand the role of courtesy, sensitivity, and perception in the culture (Helms,1999).

2.3 (SMART Objectives)

Clear & Specific: China has built vast solar and wind farms, helping fuel the growth of major industries that sell their products around the world (CNN, 2017).
Measurable: Coal still makes up the largest part of China's energy consumption, but Beijing has been shutting coal mines and set out plans last year to cut roughly 1.3 million jobs in the industry. The Chinese government has also moved to restrict the construction of new coal power plants (CNN, 2017)
Achievable: China will account for almost a quarter of global construction activity by 2030, China economy is currently transforming himself into a consumer and service led economic growth story. (Oxford Economics, 2016). Realistic: Chinese government still recognizes that the economic opportunities of the future are going to be in clean energy," said Alvin Lin, Beijing-based climate and energy policy director with the Natural Resources Defense Council (CNN, 2017).
Time-Scaled: Analysts expect China to easily meet that target. Greenpeace noted in a report earlier this year that the country's clean energy consumption rose to 12% at the end of 2015. Renewable energy sources account for about 10% of total U.S. energy consumption, according to official statistics. To help reach the 2030 goal, China is betting big on renewable energy. It pledged in January to invest 2.5 trillion yuan ($367 billion) in renewable power generation -- solar, wind, hydro and nuclear -- by 2020.

3.0 United States

3.1 Environment (PESTLE Analysis)

Political: USA has a strong democratic setup and effective rule of law, with elections that are considered fair and transparent. The country enjoys massive political and economic influence over both national and global policymaking, and is recognized as the leading superpower in the world. Economic: With a GDP of over $16.760 trillion, the US is the largest economy in the world. The economic system is well-developed and gathers its strength from its services and manufacturing industries. Social: US faces the problem of an aging population which can lead to a serious labor shortage and rising tax rates in the future. The education and healthcare system is one of the best in the world. Technological: Innovation and technology are the cornerstones of the US economy. Since its inception, the country has been leading in terms of adapting and applying technology. Though the country faces intense competition from rising economies, it is expected it will continue to retain a technology supremacy over its competitors. (PESTLE, 2016b) Legislative: United States an extremely competitive marketplace that rewards efficiency, productivity, and integrity while mandating rigorous compliance with the nation's complex rules and regulations. As the U.S. economy improves, the cost of doing business in the United States may rise. This would require a corresponding higher level of investment to compete with established domestic businesses. Federal, state, and local regulations require a thorough knowledge of tax, commercial, and labor laws. Environmental: Home to one third of the world's scientists and engineers, and accounts for one third of global R&D expenditure. Technological innovation within the private and educational sector has been increasing, with each sector accounting for 70.0% and 14.0% of innovations, respectively. The government's R&D is focused on defense (58.3% of its R&D budget) and the trend may continue for the next couple of years. ICT will also remain a driving force of the US initiative (Ogilvy, and Follow, 2016).

3.2 Business Opportunities (SWOT Analysis)

Strength: Highest value investment on R&D and Education. The world's largest economy, having GDP approximately $14.26 trillion (2009), almost 3 times the size of Japan's economy (2nd largest economy). Weaknesses: A fiscal deficit that is increasing, external debt was $13.6 trillion (2008), making it the biggest debtor country. Being called a "free market economy", the government regulates certain sectors especially the energy and the agriculture sector intensely. Opportunities: The country can support different adjustments by strong national saving that would avoid the burden of falling on both investment and growth. Treats: Deficit of the country has been coined as unsustainable according to IMF that would have undesirable effect on the interest rates and capital markets globally (Rind, C 2017).

3.3 (SMART Objectives)

Clear & Specific: According to a new report by Timetric's Construction Intelligence Center (CIC), the US construction industry is set to pick up over the next five years. (Timetric,2017)
Measurable: Timetric forecasts that the construction sector's average annual growth is set to accelerate in real terms from 1.7% during the review period to 3.1% over the forecast period, increasing from $1.0 trillion in 2014 to $1.1 trillion in 2019 in real terms. (Timetric, 2027)
Achievable: Investments to modernize the country's aging infrastructure and renewable energy sector, alongside the growing population which will generate demand for residential buildings, will be part of a number drivers of this growth. (Timetric 2017)
Realistic: Residential construction was the largest market during the review period and will retain this position, mainly supported by the government's plans to increase the budget allocation by 1.9% to $46.7 billion in 2015. The budget will support homeownership, sustainable community development and access to affordable housing to protect homeless and vulnerable families.

Time-Scaled: The country's total population is expected to increase from 321.2 billion in 2010 to 338.0 billion by 2020*, which is expected to further increase demand for housing over the forecast period. (Trimetric, 2017)

4.00 India

4.1 Environment: (PESTLE Analysis)

Political: Being one of the largest democracies in the world, India runs on a federal form of government. The political environment is greatly influenced by factors such as government's policies, politician's interests, and the ideologies of several political parties. Economic: The country registered a GDP of $5.07 trillion in 2013 following a further improved GDP growth rate of 5% in 2014 as compared to 4.35% in 2013. Social: India has a population of more than 1.2 billion people with about 70% between the ages of 15 and 65. Therefore, there are structures with percentages according to age. These structures contain varying flexibility, in education, work attitudes, income distribution, and so on. Technological: The country possesses one of the strongest IT sectors in the world, promoting constant IT development, software upgrades and other technological advancements. Recently, India has also attempted to launch their satellites into space. Legislative: Legal changes have been implemented in India, such as recycling, minimum wage increases and disability discrimination, which has directly affected businesses there. Environmental: the quality of air in India has been adversely affected by industrialization and urbanization, also resulting in health problems. As a result, there have been establishments of environmental pressure groups, noise controls, and regulations on waste control and disposal (PESTLE 2016c)

4.2 (SWOT Analysis)

Strength: Skilled workforce and huge talent pool (4.4 MN graduates and postgraduates join the workforce annually). Specialized labor pool from existing knowledge process outsourcing (KPO) (India was the first to enter the outsourcing and offshoring market). Favorable and supportive policies for offshoring. Larger English-speaking workforce, compared to other offshore destinations Weaknesses: Time-zone difference with the US. Focusing on developing infrastructure in tier-II cities, but experienced talent pool is not ready to move there. Tier-II cities lack in skill availability at mid- and senior-level management. Opportunities: Tier-II cities are one of the most cost-effective destinations in the world Increase in workforce and talent pool in tier-II cities. Treats: Rising operating costs in tier-I cities (salary increase and rise in rentals). Competition from new offshoring locations such as China and the Philippines (Reporter, B 2013)

4.3 (SMART Objectives)

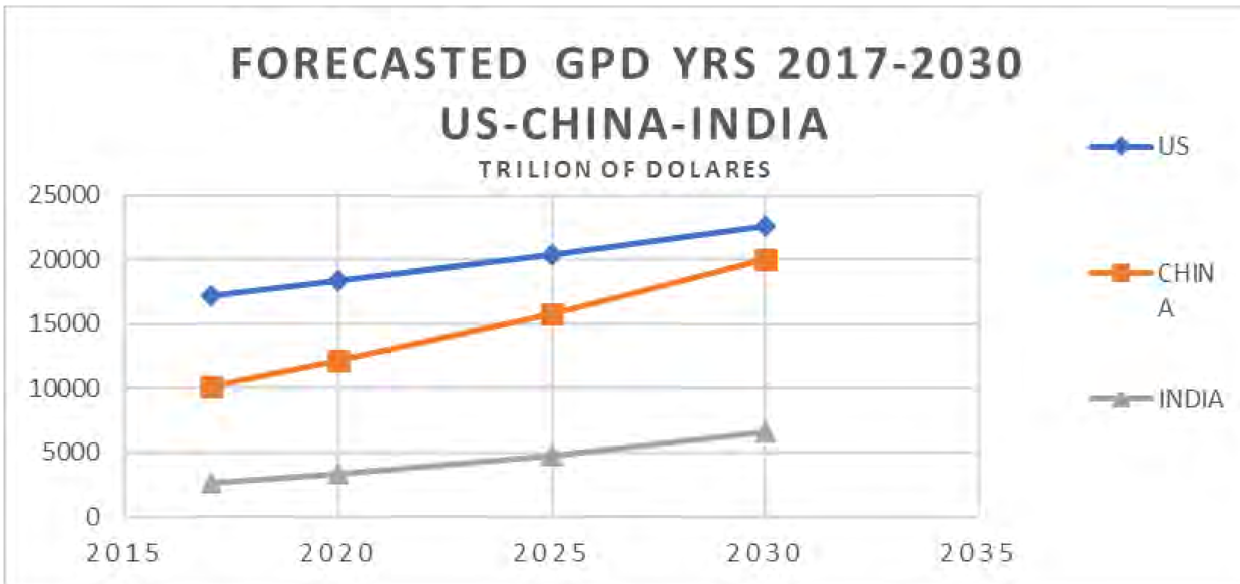
Clear & Specific: India will become the world's third largest construction market by 2025, adding 11.5 million homes a year to become a $1 trillion a year market, finds a new study by Global construction perspectives and Oxford Economics (Economictimes, 2017).
Measurable: Mr. Lafont points out that Lafarge opened a research laboratory in India to promote innovations "that are closer to the market, even for traditional methods of construction." His focus is going to be on India's booming Tier 2 cities, and not just in any one region (Economictimes, 2017).
Achievable: Lafarge would like to see in India is a "simplification of the framework of regulations so projects can move faster," clarifying that this is not a unique Indian problem, it is also the problem with many European countries. (Economictimes, 2017).
Realistic: Speaking to ET, Bruno Lafont, chairman and CEO of international cement major Lafarge said that this benchmark study reinforces why Lafarge finds India attractive, even though the study has reduced India's short-term growth prospects. "The attractive growth of the construction industry will be higher than the short term economic growth (Economictimes, 2017).

Time-Scaled: The GCP study also predicts that while India's infrastructure market is expected to grow at around 8%, the fastest among its sector, India is unlikely to achieve its plan target of $1 trillion investment in infrastructure, given the shortage of financing (Economictimes, 2017).

10. Discussion

The most recent GDP values projected for all Economies of the word, was released by the Economic Research Service of the USDA in December 2017, and shows a USA GDP value of $17,236 trillion dollars for year 2017, which confirms that in terms of GDP the USA economy is the strongest in the world. The second largest projected GDP for year 2017, is the on for China with the value of $10,123.07 trillion dollars. Considering the growth rates of these two economies it is projected that by the period 2030-2035 the China GDP will be overtaking USA (Table1).

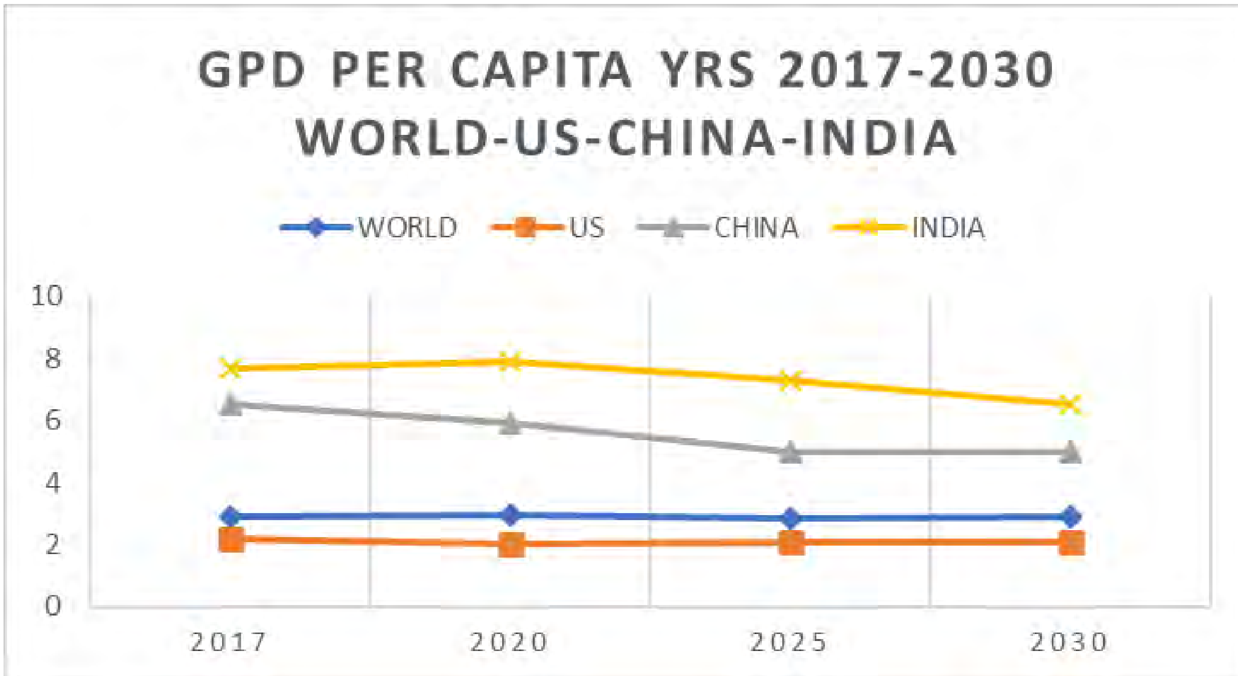
Table 1



Source: USADA United States Department of Agriculture, updated 12/06/2017

The GDP projected for India for Year 2017 is 2638.58 trillion dollars, and for year 2030 it will be in the value $ 6626.29, which indicates 151.51% increase in the period. Comparing data from the three Nations of this study, India shows the fasted growth rate between the three Nations (Table 2). The GDP per capita for years 2017-2030, indicates that India and China will have a GDP per capita growth highest than the GPD per capita of the world, and the USA will have a GDP per capita growth lowers than the GDP per capita of the world. Since GDP per capita is calculated by dividing the GDP by the population, it is necessary to analyses the population increase trend of each Nation. The population growth rate for China in year 2030 is projected to be negative in the value of -0.124, which explains why the projected GDP per capita of China is above the world GDP per capita value. What is interesting is that the Projected GDP per capita for India for the period 2017-2030 indicates an increase in the population and a positive populations growth rate by 2030 in the value of 0.862, which is an explanation with the India economy turnover for the same period is more efficient than the ones at China and USA economies.

Table 2



Source: USADA United States Department of Agriculture, updated 12/06/2017

The Oxford Economics ranks China Economy as the main investor in Global construction by year 2030, accounting for 25% of the total forecasted Global construction market 2030. The second and third investors are respectively, USA and India that will be accountable for 32% of the total construction market in 2030. Following is the summary of each Nations construction needs and they justifications:

10.1China

China's plan for a "Silk Road" will connect over 60 economies which will greatly increase trade and bring investment to the country. Plans include modernizing road and rail links and by 2025, China continues to be the largest construction market in the world, nearly twice the size of the US market. 36% of all global construction growth through 2025 will be in China. By 2030 the amount of investment forecasted to China is 25% of the $17.5 Trillion. The aging population is increasing and the need for hospitals and health service facilities will be required. China exports 90% of its goods via sea transportation. With such a large investment being made available to help strengthen the connection of the global community's commerce. The business practices standards related to construction indicates that work relations are governed by the Minimum Wage Act of 1948 that requires permission to lay off workers if business has more than 100 employees, construction sites are described as war zones due to the high number of accidents and death on sites, Corruption is a problem, and bribery speeds up the government procurement system for licenses, permits and occupancies certificates (Yates , 2007) The types of construction services identified for China are: Housing, Transportation, Hospitals & Health Services, and Infrastructure.

10.2-United States

By 2030 the USA will sit as the second largest construction market globally. The current construction market is nearly recovered from the fiscal crisis of 2008, aside from Florida which remains at nearly 50% of what it was in 2006. The current politics of the USA has had a recent impact on the construction environment by making manufacturing products outside of the to sell within the USA more expensive due to import taxes than the costs to build the product within the USA. It is expected that because of these taxes and the rapid growth of China, it is expected that manufacturing within the US to be substantially cheaper than China. A major issue for the USA is the aging infrastructure. It is expected the USA will need $3.6 trillion in infrastructure upgrades by 2030. Four major cities make up nearly 20% of all construction within the USA so heavy concentrations of construction organizations exist in New York City, Houston, Los Angeles and Chicago. The amount of investment forecasted by 2030 *is* 15% of $17.5 Trillion. The types of construction services identified for US are: Housing, Manufacturing, and Infrastructure.

10.3 India

India is one of the most rapidly growing construction markets, predicted to take over the number third spot from Japan by 2030. They are predicted to add $1 trillion to the global growth at a rate that could reach double that of China over the next three years. India does have a substantial issue for construction, they are ranked 90 out of 144 countries in terms of infrastructure and 103 out of 144 countries for electrical infrastructure. The business practices standards related to construction indicates that work relations are governed by the Minimum Wage Act of 1948 that requires permission to lay off workers if business has more than 100 employees, construction sites are described as war zones due to the high number of accidents and death on sites, corruption is a problem, and bribery speeds up the government procurement system for licenses, permits and occupancies certificates (Yates , 2007). India's culture can have an impact on their ease of business, with the country being ranked 130 for ease of use. India does not have the financial instructions in place to finance the necessary infrastructure upgrades which requires them to venture outside of the country for funding. India is by far the best opportunity for home construction, being they have the largest housing market in the world with a need for 170 million homes over the next 15 years. The Oxford Economics (2016) states that "India needs to build 31,000 new houses a day over the next 15 years to meets the needs of its rapid growing and urbanize population". The housing demand creates a further issue when combined with their infrastructure problems, but the right contractor can turn these issues into substantial opportunities for growth. Being able to not only build the homes and the infrastructure or bring on the appropriate people and funding to build the infrastructure is an exponential growth opportunity. As infrastructure is upgraded, the expansion rate of the economy in the nation will grow driving construction up along with it. The types of construction services identified for India are: Housing, and Infrastructure.

11.0 Conclusion

The common need for Global construction projects among the countries analyzed shows that Infrastructure and Housing projects are in highest demand, covering the spectrum of rehabilitation of old structures up to new investments in those areas. Hospitals, Health Service Facilities and Transportation projects are also identified, and the common denominator is that majority of the projects solicited are classified as Mega projects. In terms of business opportunities all three markets will welcome global construction expertise to comply with the needs of each Country. Global construction organizations that can offer high bond capacity and expertise to offer design-build services to Global Engineering projects, seems to be the best fit for all three Countries, as well as construction services to attend residential projects. There are some barriers and risks that needs to be evaluated. In terms of language barriers, China is the only economy in which English is not the official language, but it is used as business language. In India, corruption, bribery, and terrorism, are issues that can be managed. Even with barriers and risks associates, the Global construction market 2030 is a solid business opportunity for constructions organizations.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Augmented Reality (AR) and Virtual Reality (VR) in construction industry: An experiential development workflow

Dr. Poorang Piroozfar
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, A.E.Piroozfar@brighton.ac.uk

Mr. Amer Essa
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, ameressa@outlook.com

Mr. Simon Boseley
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, sboseley@outlook.com

Dr. Eric R. P. Farr
NONAMES Design Research Foundation, 1249 F Street, San Diego, CA 92101, USA Eric.R.P.Farr@gmail.com

Dr. Ruoyu Jin
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, R.Jin@brighton.ac.uk

Abstract

Augmented Reality (AR) and Virtual Reality (VR) in the Architecture, Engineering and Construction (AEC) industry have a sustained track record of research and development proving both technologies to be beneficial to various stakeholders throughout the lifecycle of buildings. Previous research in different areas of AR/VR in the AEC industry is not rare but rather scattered and some areas have benefitted more than others. One of the less researched areas in this field is the workflow development of the instrument in experiential research in AR/VR. With an empirical research paradigm at its core, this paper seeks to provide evidence to bridge this gap using two generic case studies, one for AR and the other for VR. A systemic procedural process is used to explain the workflow development of both experiments aiming at establishing a method which can be adopted, adapted, or customized to best suit the specifics of any similar research project in this field.

Keywords

Augmented Reality, Construction Industry, Handheld Devices, Head-Mounted Devices, ICT Application, Virtual Reality

1. Introduction

A limited number of studies carried out on AR and VR (under 15%) have used handheld and mobile devices such as smartphones as their 'Computing Units' or 'Enabling Technologies'. This, at least to some extents, is due to specificity and costs associated with specialized Head-Mounted Displays (HMDs) and their exclusive firmware and/or software applications. Consequently this also makes it too difficult to generalize the knowledge claims of such studies as they remain very much context-specific with limited scope for triangulation of findings. However, with the development of smartphones, and affordable yet generic VR headsets, the emphasis needs to be shifted on how generic experiments can be developed using a systemic approach so that they can be used by a broader range of handheld devices and smartphones – either on their own or in combination with affordable VR headsets which can use smartphones as their core VR processing unit. The need for research instruments to facilitate, enable or support applied research, puts the systematic design of user-centered experiments at the core of empirical research in AR and VR in the AEC industry. Initially developed for different studies, two experiments have been utilized in this paper to further elaborate on their workflow and expand on two creative, systematic and customizable solutions for similar research in the field. Research is not abundant in the specific field of this study but is deemed to be of paramount importance because it can help remove the research deadlock in this area. A broad literature review on AR and VR and the use of handheld and mobile devices will be provided first. The paper then carries on with the AR experiment, for which we had no option but to use a specialized device obtained from a leading technology provider for a research project. This however, does not disqualify the AR experiment developed here to be used with less sophisticated and more affordable devices such as handheld devices and tablets. In such cases, depending on the application(s) used, minor adjustment to the model might be inevitable. The paper then moves onto the development process of the VR experiment which is intended to be used as a 3D stereoscopic experiment by research participants or project stakeholders. Given the fact that workflow development research in AR/VR is very limited in scope and number, this research is a unique attempt and probably one of the first ones in this area.

2. Literature Review

The construction industry is dependent on visual imaging solutions to accurately communicate form, functions-related and performance-related information. In this context, virtual solutions can prove far more practical than using physical prototyping due to time and cost constraints, convenience, health and safety issues and logistics (Brandon et al. 2005). Although the conceptual principles, the technology both in terms of software and hardware and the scopes, applications, purposes and applicability of AR and VR are different, their definitions, what they entail or are understood to be, and how and where they can be most beneficial, are not mutually exclusive and are still determined by subjective readings. Raajana et al. (2012) believe that confusion between AR and VR is an enduring problem. However, there is almost an incessant continuum between actual and virtual reality and several terms have been coined to denote one or the other or a mix of both. Those include amplified reality, augmented reality, augmented virtuality, blended reality, diminished reality, mediated reality, mixed reality, virtualized reality, just to name a few (see e.g. Schnabel 2009). Milgram and Colquhoun Jr. (1999), who have been referenced by many other researchers (e.g. Azuma et al. 2001, Dunston and Wang 2005, Yuen et al. 2011, Raajana et al. 2012, Meža et al. 2014), assert that there are two distinct definitions for AR in the literature. The more common one, which is built around the technology, includes hardware (a display system i.e. Head-Mounted Display (HMD) or Heads-Up Display (HUD)). The second definition, which is rather theoretical, does not necessarily involve an instrument (i.e. a display system) but represents a concept. However, what differentiates VR from AR is that it removes the real elements – regardless of the type of display device – and instead immerses the user in a totally virtual environment where virtual objects are used to represent actual reality. In either case, the virtual elements can be based on 2D or 3D objects or information, or even sound, light or scent. Efforts to establish VR outweigh those for AR and started earlier, especially in education and entertainment industries. However, over the past two decades, the applications of both AR and VR have grown rapidly due to development of mobile and wearable devices (Piroozfar et al. 2017). Bae et al. (2012) and Bae et al. (2013) developed Hybrid 4-Dimensional Augmented Reality (HD^4AR) which uses site photography to identify location and orientation of field personnel to allow them to query and access semantically rich 3D cyber-information and see it precisely overlaid on real-world imagery. Irizarry et al. (2013) use KHARMA (Hill et al. 2010) to develop an Information Surveyed Point for Observation and Tracking (InfoPOST), as a mobile AR tool for facilities managers for accessing information about the facilities they maintain. Handheld and mobile devices such as smartphones and tablets are feasible options for AR/VR systems, each of which have their own advantages and limitations for AR and/or VR applications. New advancements in software, firmware and hardware technologies have portrayed handheld devices as viable solutions for AEC applications. Research into the use of such applications is still few and far between. Wang et al. (2013) suggest that out of 38 journal papers and 82 conference papers published on AR in the AEC industry between 2005 and 2011, there were only 14.8% (N=9) where a hand-held device had been used. Combined with basic HMD units smartphones are gaining popularity and momentum as they offer a compact, affordable and agile yet multi-purpose device which combines advanced and customizable processing power with an infinite and customizable source of software technology (i.e. mobile device applications).

3. Research Design and Methodology

This paper presents the workflow of two experiments which have been developed for two research projects, one on AR and the other on VR in the AEC industry. After the research question, aim and objectives, and the theoretical framework of each research were formulated and critical review of literature corresponding to each were carried out, a task list for each project was articulated and the experiment was designed to fulfill those requirements and provide answers to the research questions. The aim of this paper is to expand on the development process of the two experiments in comparison with each other to provide an insight into the similarities and differences, possibilities and difficulties associated with each experiment. The paper sets out to establish a generic but systemic pathway for the design of such experiments. The experiential nature of both research enquiries required that experiments be designed with a very specific account of the research participants in mind:

> In the new paradigm [of experiential research], this separation of roles [of the researcher's and the subject's] is dissolved. Those involved in the research are co-researchers and co-subjects. They devise, manage and draw conclusions from the research; and they also undergo the experiences and perform the actions that are being researched (Heron 1982).

Ease of use (of both software and hardware), practicality, interactivity, active engagement were the most important criteria among more common ones such as replicability, validity, reliability, reproducibility of the instrument and the process of data enquiry and analysis in the research design. More specifically, in the process of development of both experiments, special attention has been paid to:

Value of human experience; focusing on the wholeness of experience; searching for meanings and essences of experience; obtaining descriptions of experience through first-person account; regarding the experiential data as imperative; formulating questions and problems that reflect the interest, involvement, and personal commitment of the researcher; and last but not least, viewing experience and behavior as integrated and inseparable discourses.

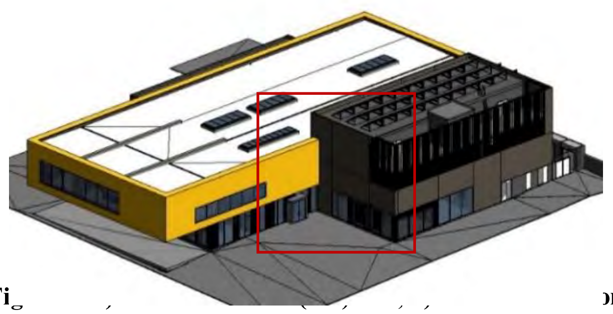
The development process of an experiment for AR from a 3D model using an industry standard BIM application (Autodesk Revit 2016) will be explained next.

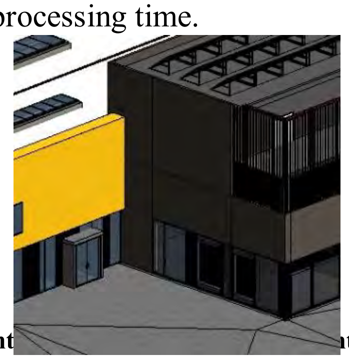
4. Development of AR Experiment

The University of Brighton's (UoB) new Advanced Engineering Building (AEB) was selected for this experiment and the development of the AR Experiment was carried out through the following steps:

4.1 Part 1: Preparing the 3D Scene

The 3D BIM model of the building was acquired from the architectural practice who were in charge of the design for this new facility, pre-tender stages (Figure 1). The aim of this exercise was to use the existing construction drawing documents and models for developing this AR experiment to avoid rework and also to test interoperability between different software applications. For the model to be viewed on a pair of M100 Smart Glasses™ utilizing AR, the first step involved ensuring all required components of the model are present, before being exported. As this experiment was designed to view the building mostly from the exterior, most of the interior of the AEB were not relevant to the experiment, hence the majority of the interior details were removed to keep the file size to a minimum, with an aim to reduce the processing time.





Fi ... omponent ... nt)

Interoperability between the AR hardware/software and 3D model is key to ensuring the model can be viewed with the Smart Glasses. The Smart Glasses utilize an exclusive operating system which is not directly operable with the BIM application file format. Therefore, the 3D model must be prepared in an application to generate a file format which is readable by the AR application installed on the Smart Glasses. Due to its wide usage, high flexibility and powerful image analysis/processing and rendering capabilities Autodesk 3DS Max was the software of choice to bridge the gap between the 3D model and the AR Smart Glasses. Moreover, 3DS Max is owned by the same software application vendor as Revit (Autodesk) which meant problems with interoperability should not occur at least at one end. The model must be exported to a file format native to the AR hardware. For this purpose .fbx format was selected, which is a proprietary file format used to provide interoperability between digital content creation applications.

4.2 Part 2: Importing the Scene into AR Environment

After the model was imported into 3DS Max (Figure 2a), the process of generating the AR scene could begin. This includes the generation of a 'marker' to assist the Smart Glasses with when and where to display the model. Upon inspection after the first run-through, it was found that the materials on the AEB building had seemingly been lost, meaning the building was displayed as a series of grey-colored plastic components, as shown in Figure 2b.

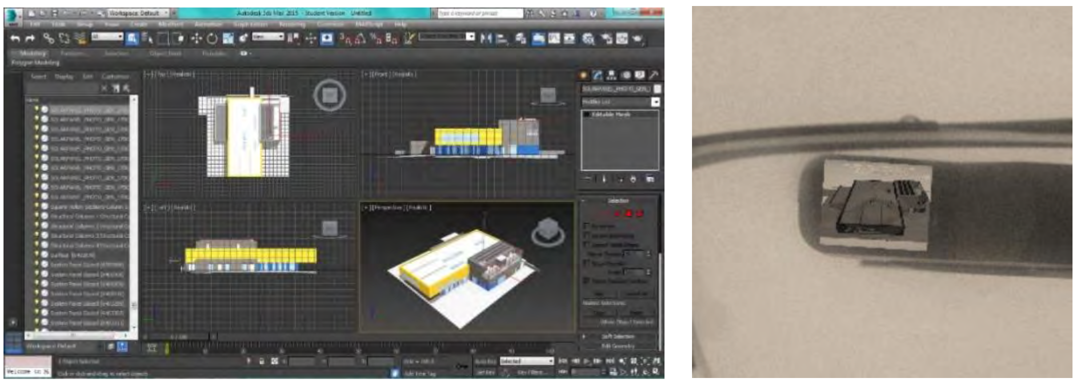


Figure 2: a) The model imported into 3DS Max using .fbx file format, and b) greyed-out AEB building through AR Smart Glasses

Ultimately, this is due to the materials being native to Revit, but not to 3DS Max. Even though the materials appear to have been imported into 3DS Max with the model (as shown in Figure 2a), the augmentation showed this not to be the case. Therefore, the materials must be manually applied to each component using the Materials Editor tool in 3DS Max. Once the materials native to 3DS Max had been generated and applied to all components (Figure 3a), the generation of the scene could then progress. This involved the use of 'AR Media', an AR plugin compatible with the Smart Glasses software, to export the scene (Figure 3a) and to create the marker (Figure 3b).

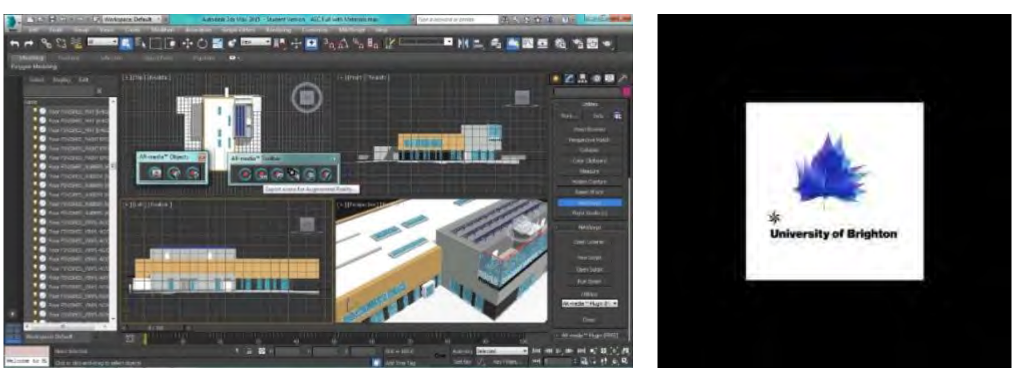


Figure 3: a) The model being exported using AR Media after materials being applied in 3DS Max, and b) The marker being created using AR Media

Once the AR model was exported from 3DS Max, it needed to be downloaded onto the Smart Glasses via the AR Media application using a Wi-Fi connection. Smart Glasses will then display the 3D Revit model if the customized marker is sighted. The projected visual data (in perspective) before and after the marker is sighted are illustrated in Figure 4. It should be noted that the size of the augmented model relates to the size of the marker when printed, and increase in marker size results in a larger augmented model.

Figure 4: Smart Glasses view a) before, and b) after sighting the marker

5. Development of VR Experiment

The same building (UoB's AEB) was used for this experiment and the development of the VR experiment included the following steps:

5.1 Part 1: Preparing the 3D Scene

A 3D model and a 3D scene are required for this exercise. This can be created using a 3D modelling software or by importing an existing 3D BIM model from supported software applications. In this experiment, the model was developed from scratch in SketchUp™ (Figure 5a).

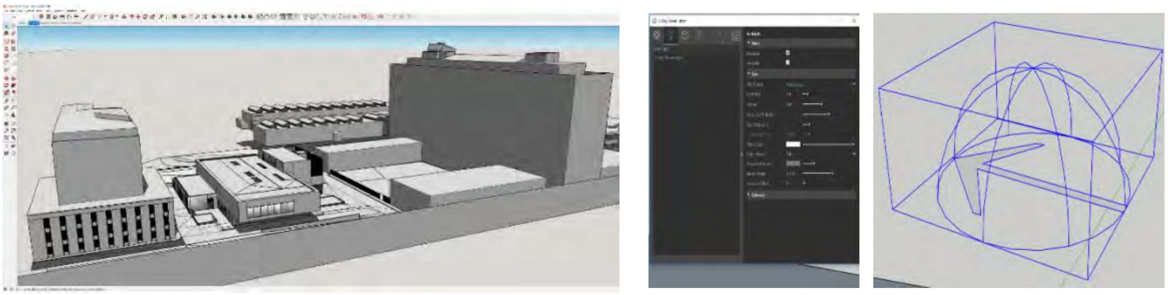


Figure 5: a) SketchUp model of the building, b) Lighting options and, c) Light dome in model space

Had BIM model (e.g. in Autodesk Revit) been used, it could have been setup in 3DS Max, exported as a compatible file into SketchUp to start the project, which may have added some additional steps required to address compatibility and rework. The alternative route in this experiment has been taken intentionally to avoid such complications and to provide a proof of concept as to how alternative routes, compared to the one taken for the previous experiment, can be used. This workflow, however, is not obligatory and is dependent on user preference, knowledge, and ability, the project timeline and budget constraints, and access to various software packages which may also entail potential problems with interoperability and cross-compatibility. At the next step, materials and textures are set up and assigned to the 3D model and the lighting parameters are configured to suit, using V-Ray™ (Figure 5b and 5c). For this purpose, V-Ray 'plug-in' can be utilized to render and export relevant images. It supports different digital content creation applications such as SketchUp (as shown here), 3DS Max, Revit and Maya.

5.2 Part 2: Generating a Cubemap

Once the scene was completed with finalized geometry, materials and lighting setup, a Cubemap – a series of six images assembled together to create a full 360˚ view – would have been ready to be rendered in V-Ray. In the case of stereoscopic views, as in this experiment, two cubes are used requiring twelve images. This can easily be set up in V-Ray. Then the Cubemap dimensions should be set up as per the mobile device's display resolution. After setting up the resolution, the scene will then be rendered (Figure 6).

Figure 6: Rendered stereoscopic Cubemap (12-sides, 6 per eye)

5.3 Part 3: Utilizing Cubemaps

Cubemaps (using image file formats such as JPEG, PNG etc.) need to be uploaded to an application which supports mobile VR using Cubemaps. In this case, an online open source application has been used which also supports standard 360˚ (non-Cubemap) panoramas. As walkthrough function was intended for this experiment, the application should also support this function. The walkthrough option was selected and set up which requires uploading more than 1 Cubemap. Subsequently each Cubemap, should be edited and assigned a starting view as desired (Figure 7). 'Hotspots' – visual markers that direct the user to alternate Cubemaps – were set up with a chosen graphic overlay – in this case arrows – and placed at a suitable point within the viewer's perspective indicating the suggested location the hotspot will deliver the user to (Figure 7). A link to the VR project was created and shared via the Projects Overview page, enabling access without the need for account registration or login.

Figure 7: Utilizing Cubemaps and setting up hotspots

5.4 Part 4: Viewing the Project

Once the project was loaded via the web address or directly within the projects page, the VR icon can be selected to enable Stereoscopic view (Figure 8a). A HMD VR viewing hardware for mobile devices is required for this function. The user viewing preference and the mobile device may also need to be calibrated for VR using the VR Setup function (Figure 8b). This may vary depending on the mobile device and application(s) used.

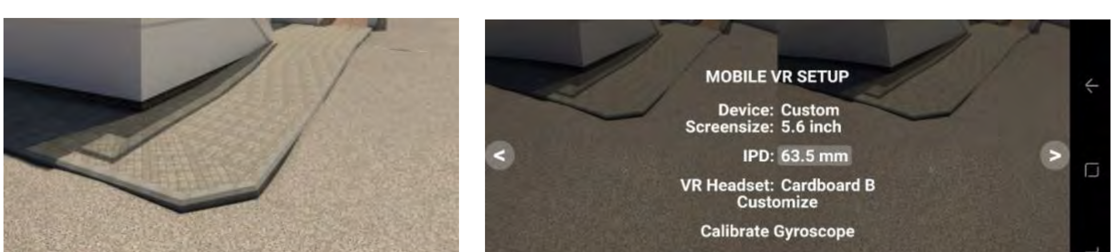


Figure 8: a) Enabling the stereoscopic view and, b) calibrating the mobile device and user viewing preferences for VR

Finally images can be navigated through by hovering the marker over hotspot icons or arrows if in VR mode (Figure 9a) or by clicking on hotspot icons or arrows when not in VR mode (Figure 9b).

[illegible]ow in[illegible] and, b) clicking on hotspot arrow in non-VR mode

6. Concluding Comments and Future Research

Previous research in AR/VR in the AEC industry indicates a gap in how the experiments can be developed and used as data collection/analysis instruments for user-centered research. Particular attention should be paid to the participants in experiential research as no longer does the traditional division between the researcher and the subject exist and the participants will have a new role of co-subjects/co-researchers. Two experiments were developed to ensure the ease of use, applicability and fitness to serve the purpose of the studies for which they were designed. For the specific purpose of this paper, the experiments were then revisited and redesigned to ensure that they stay generic and present a customizable workflow which can be adopted and adapted to the specifics of similar research in the field. Despite the expectations, the software applications – even those provided by the same vendors – remain, to some degree, incompatible, and their interoperability is still an outstanding issue. However, there is a common logic behind how such experiments can and should be developed and this paper tried to shed some light on such logic by presenting a systematic workflow for an AR and a VR experiment. Interface tracking, visual clarity, intuitiveness, cost effectiveness, swift customizability, control over unlimited design variations and visualization parameters are just to name a few advantages which can be realized through an effective workflow design for an AR/VR experiment. Although the AR experiment seemed to be more straightforward, the issues regarding interoperability and file transfer and extra preparation work was heavier than what appeared to be in the development of the VR experiment. Besides, the local and global registration of the virtual entity still remains a major hurdle on development of an effective AR solution. The bridges between actual and virtual realities are still inept and real-time registration is far from reach, chiefly due to shortage and inefficiencies in hardware, software, processing speeds and web technologies. This paper helped improve our current understanding of logic, procedure and process of how different technologies can work together and/or be deployed to enable AR/VR as a research instrument for experiential research in this area. The user experiment is key in such research and was accounted for during the first stage of development. This paper also revealed that further work in this area is still very much needed. Future research in this area can benefit from closing the circle through a feedback loop from the participants, not only about the main research question but also about how they found the experiment itself. Further areas which can benefit from the two procedural experiments explained in this paper are yet to be explored in more detail. Although coding might not be a favorable area, there are still opportunities in this area to be explored more and with Visual Programing Languages (VPLs) becoming popular, opportunities are arising to offer more adjustable/ customizable options for the design and during the application of such experiments.

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The application of Augmented Reality (AR) in the Architecture Engineering and Construction (AEC) industry

Dr. Poorang Piroozfar
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, A.E.Piroozfar@brighton.ac.uk

Mr. Simon Boseley
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, sboseley@outlook.com

Mr. Amer Essa
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, ameressa@outlook.com

Dr. Eric R. P. Farr
NONAMES Design Research Foundation, 1249 F Street, San Diego, CA 92101, USA Eric.R.P.Farr@gmail.com

Dr. Ruoyu Jin
School of Environment and Technology, University of Brighton, Brighton, East Sussex, BN2 4GJ, United Kingdom, R.Jin@brighton.ac.uk

Abstract

Augmented Reality (AR) as a concept has been in use for many years and prevalence of new mobile technologies, such as smartphones and handheld devices, have facilitated the concept of AR becoming fully realized. Various fields are exploiting the increasing feasibilities the concept of AR can offer; one of these being the Architecture, Engineering and Construction (AEC) industry. This paper introduces a research project that investigates benefits and limitations of AR for use in AEC industry. It starts with a brief background to the research before presenting a critical literature review, which forms the basis for the development and design of an AR experiment and a questionnaire for participants in the study. Results are provided with an in-depth discussion on their possible significance, before a conclusion is presented. The results suggest that although the participants believed that AR can offer a wide range of benefits to different tasks and at different stages of a project, it seems more beneficial to some specific tasks or at some specific stages than the others. Using the specific findings of this study future research in this field is proposed in different areas.

Keywords

Augmented Reality, Construction Industry, Handheld Devices, ICT Application, Virtual Reality

8. Introduction

Augmented reality (AR) and Virtual Reality (VR) have found momentum in the Architecture, Engineering and

Construction (AEC) industry. As AR has become an increasingly feasible concept, opportunities for its use are expanding and leading to innovation in various fields. The fields which augmented reality can be applied to, as discussed by Azuma (1997), are diverse. One such field that shows potential for adopting AR is the 'prevalently visual' AEC industry. Due to the nature and context-specifics of the AEC industry however, in-depth and specialized research in this area seems to be few and far between. This study aims to explore the possible uses of AR in the construction industry as well as the potential solutions it could provide as a tool in various construction related tasks, gauging the benefits and limitations associated with the concept. In order to realize this aim, a practical experiment has been developed as an instrument to conduct a problem-solving approach to the study. A questionnaire has been designed and used to gather quantitative and qualitative data in order to analyze the feasibility of using such methods in the construction industry. The results suggest that although the participants believed that AR can offer a wide range of benefits to different tasks and at different stages of a project, it is deemed more beneficial to some specific tasks or at some specific stages than the others.

9. Literature Review

Augmenter Reality (AR) is essentially a form of Mixed Reality (MR) and can be defined as the concept of integrating virtual elements (generally, computer generated) onto the user's real world environment (Azuma 1997). Several terms have been used to define the spectrum between actual and virtual reality: amplified reality, augmented reality, augmented virtuality, blended reality, diminished reality, mediated reality, mixed reality, virtualized reality, etc. (e.g. Schnabel 2009 among others). Widely referenced by many researchers (e.g. Dunston and Wang 2005; Azuma *et al.* 2001; Yuen, Yaoyuneyong, and Johnson 2011; Raajana *et al.* 2012; Meža, Turk, and Dolenc 2014), Milgram and Colquhoun Jr. (1999) assert that two definitions for AR exist in the literature. The first and most common definition includes a display system such as a Head-Mounted Display (HMD) or Heads-Up Display (HUD) whereas the second definition is more general without a reference to a display system. These virtual elements can be 2D or 3D objects, or even sound, light or scent. The features of AR permit the user to follow their viewpoint by means of a tracking system, superimpose virtual objects onto the user's view of a real-world scene, render the combined image of virtual objects and a real-world scene in real time and locate virtual objects in a real world scene to the correct scale, location and orientation (Shin and Dunston 2008).

Key benefits of using AR applications were found to improve communication between all parties involved, increasing project understanding and accelerated decision making, better scheduling and budget-management, real time visualization, enhanced collaboration, increased safety and greater implementation of BIM (Jones 2014). The literature also highlights differences between the countries (Greenwood *et al.* 2008) in terms of the perception and the uptake of such technologies which would suggest that VR/AR applications could be used more frequently if attitudes and popularity of these technologies change. It is suggested that the construction industry is heavily dependent on visual imaging solutions to accurately convey form and performance information, where virtual solutions such as AR can prove far more practical than using physical prototypes due to cost, potential risks and logistics (Brandon, Li, and Shen 2005). A study (Shin and Dunston 2008) highlights eight areas which they consider suitable for AR applications, including: site layout, excavation, positioning, inspection, coordination, supervision, commenting, and strategizing. Conversely, it was also concluded that there may be certain tasks that would derive little to no benefit from utilizing AR solutions. However, what seems to have gone unnoticed not only in this study, but much more widely, is design, ranging from architectural design to detail development and from structural design to building services. Moreover, activities more specific to refurbishment, restoration and remedial work on, and maintenance of, existing buildings, where AR can play a major role to cut the cost and time, and improve on quality, as well as health and safety pertaining to such activities are not included.

It was found that except for a couple of specialized suppliers, offering specifically developed hardware gears at rather expensive prices, currently there are not many affordable solutions employed on a large scale to provide a benchmark for quality application of AR in AEC industry. The literature does however, illustrate a general modus operandi among developers for the assembly of AR systems. Other researchers have discussed the use of animation in construction through the 'traditional' configuration, including the use of a new customized software framework developed specifically for animation purposes (Behzadan and Kamat 2009), but problems were found in display of animation in combination with GPS. Follow-up work suggests that virtual elements should be displayed as independent entities, so that each object's respective position, orientation and size can be changed independently (Behzadan and Kamat 2011). Another study (Malkawi and Srinivasan 2005) presents an AR framework which allows interaction and visualization of buildings and their thermal environment. Named Human-Building Interaction (HBI) Model, the proposed AR system, consists of four components, where It was shown that the system works well in permitting the user to see the thermal environment of a building and that the HCI component improved use of this system significantly. Other research (Fuge *et al.* 2012) gives account of developments on the use of gesture recognition AR where the results indicate that it can be integrated successfully into systems, improving ergonomics of AR applications. One of the most significant barriers to successful operation in the last two studies remains to be the issues with registration (Azuma 1997) which occurs when the positioning of the virtual objects fails to display at the correct location in the real world. To address this problem AR systems may employ 'markers', a visual cue, placed on site to improve software/hardware recognition and these work as location targets to define where the virtual objects should be displayed. The use of markers can increase robustness and reduce computational requirements (Park and Park 2010). The disadvantage of marker-based systems is that they are often visually intrusive or unappealing. A hybrid alternative to ordinary marker systems is proposed to overcome this issue (Park and Park 2010). The solution was to use invisible markers by application of UV ink.

AR systems can also use smartphones, tablets or handheld devices as an alternative option. Modern day advances in handheld devices allow certain AR solutions to become viable for AEC applications. Research into their use for this application remains limited at this stage. A review of mainstream studies (Wang *et al.* 2013) suggests that there have been 38 journal papers and another 82 conference papers filtered out of initially 154 identified papers published on AR in the AEC industry between 2005 and 2011, where only 14.8% (N=9) were carried out using hand-held devices as their 'Computing Units' under the 'Categories of Implementation' or 'Enabling Technologies' as suggested in this paper. Construction Opportunities for Mobile Information Technology (COMIT) does provide some precedent in this case. One of COMIT's recent projects carries out research into the use of augmented reality in construction, where HoloLens have been used to implement Augmented Reality to visualize 3D/4D in site and in 1:1 scale in a Balfour Beatty project.

10. Research Design and Methodology

The aim of this research is to determine the suitability of AR for the construction industry and associated tasks, gauged through the perceived benefits and limitations of the concept and technology through use of mobile and handheld devices. Secondary research was carried out by means of a literature review to build an extensive knowledgebase and understanding for AR to then be used in the design of the research instrument for this study. Primary research was undertaken utilizing a mixed-methodology approach to overcome limitations which may be imposed by a single method approach. This would be achieved through quantitative and qualitative means, by way of a questionnaire after the participants took part in an experiment developed for this study. Particular care was taken to adapt primary research methods in the most appropriate manner in order to mitigate the fact that AR can be seen as a complex and/or confusing topic to those who may have limited exposure to the concept in its intended context of application; a less considerate approach could have resulted in misrepresentation of, or at best case scenario an unintended bias in, findings. Pivotal to the data collection instrument of this study was the experiment design which was developed following the break-down of the tasks and intentions required to be fulfilled for the specific purpose of this study.

10.1 Development of Experiment

The search for a platform in which to create a suitable AR application was carried out extensively over a significant period of time. Many Smartphone- and Tablet-based solutions, applications and methods were trialed to gauge how effective they could be for providing a workable design visualization solution. A suitable application called 'LayAR' was eventually found that would fulfil most of the requirements set out in this research. LayAR is not essentially designed for use in the AEC industry but rather as an AR browser. LayAR is easier to use and setup compared to some other applications designed with the same purpose. It supports 2D images, 3D models, sounds and video as AR information which are given a location-specific address. Initial experimentation found that the process of creating and implementing customized AR content remained a relatively complex task, but was still significantly easier than some other applications tested.

At this point, a web-based solution called 'Hoppala Augmentation' was found to aid automation of the process of integrating AR content (images, 3D models etc.) without the need for computer coding which makes the system more intuitive. The process works by 'uploading' an image or 3D model file to the Hoppala online database, the user then enters location data for the AR content by providing latitude and longitude, altitude and scale information. Hoppala then generates a code which is sent to LayAR to publish the content.

The first successful trial of this method used a 2D image file of a skyscraper building design created by the researchers. The general feeling was that the concept did work but there were issues with performance; the GPS continually refreshing itself making the image appear to 'skip around' the user display, where the location of the object changed with renewed GPS data. This was resolved by fixing (setting) the location of the device at a certain latitude/longitude. This solved the issue, but meant that grid coordinates are required and that the GPS component could not be used. This is perhaps the ideal solution until advancements are made with internet, hardware or software to allow increased performance or else an interface would be required to link to an external GPS tracker to an IPS (Indoor Positioning System) receiver to assist the app to locate the model on the site context in real-time. It was decided that improvements should be made to increase clarity of information shown. This would be achieved by using 3D models rather than 2D images, as shown in Figure 1a. Using 3D models allow the user to, in a sense, walk around and inside the building/or structure (3D object), as shown in Figure 1b.

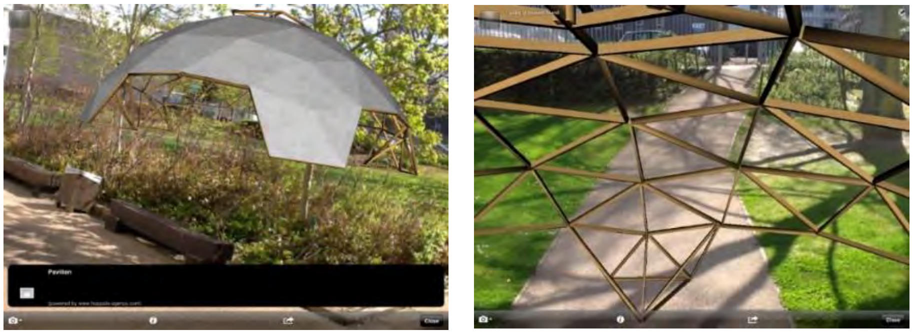


Figure 1: AR experiment developed using fixed location: a) pavilion structure in the context (left); b) pavilion structure's internal perspectives (right)

In comparison to earlier methods tested, the selected solution is more effective at presenting information as well as being more interactive and as such, is more likely to involve users through design stages.

10.2 Questionnaire

Informed by the findings of critical review of literature, the questionnaire was designed and split into four sections as follows: General Information: to identify respondent backgrounds; Knowledge of AR/VR: to assess respondent understanding of AR; AR in the construction industry: to measure participant's view on suitability of AR to construction tasks; and Study Focus: to gauge feasibilities of adopting AR solutions in construction industry. Most questions were multiple choice or Likert scale in nature. However, the participants were provided the opportunity to expand on their responses wherever deemed necessary. Prior to the questionnaire being finalized, a pilot was undertaken to ensure clarity, integrity and the flow of the questions and also to ensure that any possible bias – positive or negative – is strictly avoided.

10.3 Data Collection

Respondents were selected using Purposive Sampling techniques on a university campus where the only requisite was having an academic background (being a student or a member of staff), to ensure a common degree of understanding and knowledge of the field of application exists between the survey participants with no need to have prior experience of AR in the AEC industry or otherwise. The sampling was intentionally aimed at audience at a university setting as most participants were expected to be young future professionals as rather tech-savvy and more likely potential users of modern technologies in their professional career. The questionnaire analyzed participants' opinions on how intuitive the application was and the perceived level of values it could offer to factors such as productivity. Before the questionnaire was presented to respondents for data collection, a pilot study was conducted to prevent possible issues/errors occurring.

11. Results and Discussion

Part 1 - General Information: The respondents were asked about their career or field of study. This information was required to gauge the level of knowledge regarding the study topic in particular and the construction industry in general. Most of the participants (76%) had a background in construction. The experimental AR system was developed for architectural design tasks, so with most participants being students in relevant disciplines, the demography is apt to the investigation.

Part 2 - Knowledge of VR/AR: When asked if they had heard of VR/AR and if yes in what capacity, 70% of participants stated that they had heard of VR with only 62% for AR. For those that replied 'Yes', the most popular application of VR was for use in games and films. When asked 'If applied, in which area do you think VR or AR would be most useful?', the outcome showed the applicability of these concepts not only to construction as highest (N=21) but also into other industries with Entertainment N=17, followed by Military and High Risk Training, N=11 and 10 respectively, with

Manufacturing, Education and Social Networking with N=5,4,3 at the bottom of the table. This demonstrates that perceptions toward the applicability of AR for construction are generally positive. The unexpected anomalies here seem to be Education and Social Networking where only 4 and 3 people believed that VR and AR would be most usable.

Part 3 - Use of AR in the Construction Industry: The experimental AR system was introduced to participants to gauge their opinion on use of such a system in the construction industry and analysis of the system itself. Part 3 is designed, considering the RIBA plan of work, to justify the use of AR through pre-construction, construction and post-construction phases. It focuses on various tasks under these phases to judge overall applicability. The participants were asked in which areas they think AR is most applicable, if used in the construction industry. This question draws upon the users' experience of the presented AR experiment to gauge participants' opinion on applicability pertaining to the listed tasks. Likert scales were utilized to classify a level of applicability. Users were asked to give their verdict on the perceived benefit of the AR system to pre-construction phase of works such as design, project management and site management. The results showed a mixed outcome in respect to pre-construction tasks, with the general viewpoint being that the concept lends well to design tasks better than others (Figure 2). To summarize, AR seems to be applicable to the various phases of works set out under the RIBA plan of works, according to the views of the questionnaire respondents. This supports the view that AR would be useful for construction tasks but would have needed more work in some certain areas (such as project/site management as well as inspection and maintenance) than the others, should its wider and deeper application in the AEC industry be intended.

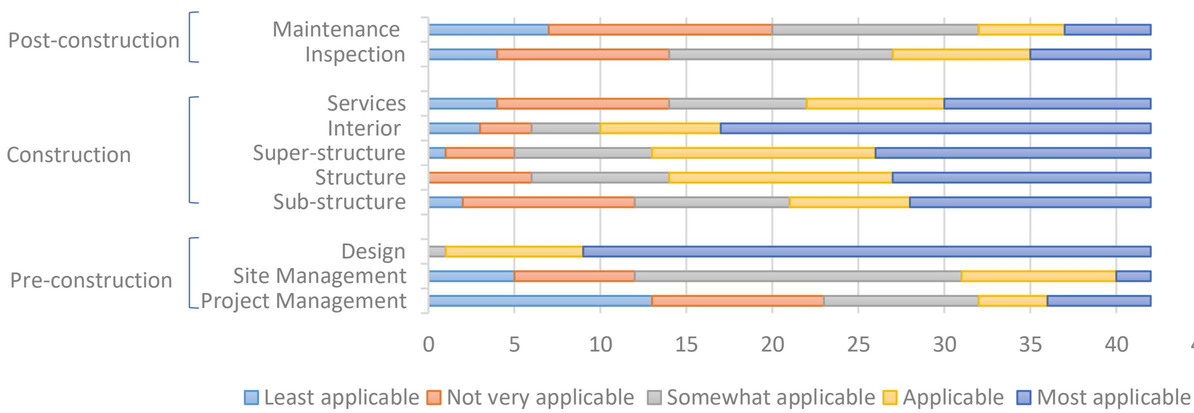
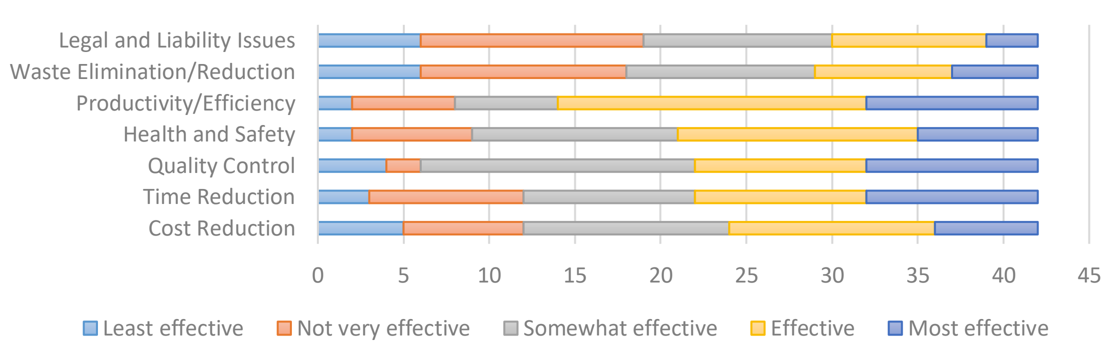


Figure 2: AR Applicability to different stages at pre-, in- and post-construction phases

Part 4 - Study Focus: Part 4 aims to measure the potential benefits AR could bring to the construction industry and the overall feasibility of its introduction. Questions cover factors such as cost, time and obstacles associated with integrating AR in construction. The participants were asked how effective they think the application of AR could be in construction tasks/goals regarding a series of issues as listed in the question. Here, participants' experience of the experimental AR application was used to gauge their opinion of the efficacy of applied AR systems. Overall, the findings showed that respondents believed AR can provide benefit to construction tasks (Figure 3).

Figure 3: The effectiveness of AR for different tasks/goals pertaining to a construction project



The answers to the question: In your opinion, how effective a tool is this in encouraging the client's participation in the design and construction process?' showed that the majority of respondents (90.5%, N=38) agrees that the application would be an effective or a very effective tool for encouraging user's and client's participation in construction tasks. This indicates the potential for such technology to change the way in which issues between construction professionals and clients are negotiated and resolved, with assistance of improved visual communication. To gauge the feasibility of introducing such an application into construction projects, the participants were then asked if they employ such solutions if they were in charge of a project. 74% (N=31) stated that they would do where 19% (N=8) were undecided and only 7% (N=3) said they would not employ such technologies if they were in charge, mostly due to time and costs involved.

Another question was asked to find out with all realistic potentials and hindrances on the way of employing such technologies, if the participants think this is a way forward in the construction industry. Results showed that 93% (N=39) of the participants believed, despite potential issues and constraints, that the integration of AR solutions would be the way forward for the construction industry. This result demonstrates little doubt that AR has potential for use in construction tasks. The participants were then asked if they thought this was the way forward, how long they envisaged it would take for the construction industry to pick up those technologies. 45% (N=19) believed that it would take around 5-10 years for the UK construction industry to pick up such technology, while the same number thought it would take up to 5 years. Only one respondent (2%) believed it would take more than 10 years to implement those technologies and 7% (N=3) did not answer the question.

To further investigate what might be perceived as a hindrance, the participants were asked what, in their opinion, might be the most significant barrier to wider implementation of such technologies.
This question assesses which of the key factors listed, was felt to be the most significant barrier preventing AR solutions from being implemented in the construction industry. Respondents were also given the opportunity to specify other reasons. Respondents identified cost as the leading factor (25%, N=11). Other top factors selected were the need for change (18%, N=8), time (15%, N=6) and attitudes (15%, N=6). Issues regarding attitudes toward the technology could be the most difficult to resolve; as where the industry may uphold traditional values, it may be difficult to persuade staunch perspectives otherwise. However, most factors represented are interrelated and where one factor can be mitigated, others can be too respectively.

12. Concluding Comments and Future Research

The findings of this investigation suggest that AR solutions can provide a functional use to the various facets of the construction industry. Although diverse in possible applications to construction related tasks, AR and its perceived benefits may be more suited to certain tasks than the others. Design and inspection related tasks were concluded to be more befitting in its use. Among potential uses for the technology, one such interest is the opportunity to aid communication, information exchange and involvement with/of clients during the design phase. Subsequently, issues caused by lack of clarity and understanding could be addressed.

The research highlighted that many models exist, be it software or hardware systems, which can be used to implement AR solutions. Furthermore, new and modern mobile devices such as smartphones, tablets and handheld devices are replacing conventional methods which were relying on preliminary hardware such as HMDs and laptops backed up by external GPS receiver or GPS total stations. Developments in hardware are improving user-friendliness, producing refined ergonomics, increasing computing power and accommodating integrated software, components and tools e.g. built-in cameras, compasses, GPS, etc. These improvements are yielding increasingly viable options for AR solutions and methods of their implementation, thereby improving the efficacy of AR to be used as a tool in the construction process and demonstrating the need for a review of up-to-date methods.

The consensus towards AR shows that the technology can be a way forward for the construction industry, with the general stance on its use being largely positive. Despite such perceptions of AR, the investigation shows there is a common sense of obscurity about AR; many are unfamiliar with what AR is and particularly, how it differs from VR. This indicates that such technology and its application need to be introduced better and promoted more profoundly, probably much earlier on and as a part of formal curriculum in higher and further education.

The biggest factors affecting implementation of AR solutions in the construction industry are perceived to be: i) Time needed to implement the technology/technologies; ii) The financial cost to adopt the related hardware and software systems; and, iii) The discerned need for change and attitudes toward the technology.

The finding of this research may be used to help inform the future of research and practice of AR (and to some extents

VR) in the AEC industry. More resources can be redirected into areas which were picked up in this research as areas where such applications are considered to be under-utilized or less likely to be used.

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Field Evaluation of Surface Characteristics of Microsurfacing Pavements

Yi Jiang, Ph.D., P.E.
School of Construction Management, Purdue University, West Lafayette, Indiana, USA
jiang2@purdue.edu

Shuo Li, Ph.D., P.E.
Division of Research and Development, Indiana Department of Transportation
West Lafayette, Indiana, USA
sli@indot.in.gov

Abstract
The Indiana Department of Transportation (INDOT) started to experiment with microsurfacing in pavement surface preservation. In order to provide first-hand, original data to better utilize microsurfacing in pavement surface preservation, a study was conducted to evaluate the surface characteristics of microsurfacing, in particular the surface friction properties. A total of six microsurfacing pavements were selected for field evaluation in this study. Field tests were conducted to evaluate the performance of microsurfacing, including pavement surface friction, surface depth and surface smoothness. Friction numbers were measured on freshly placed microsurfacing and as well as over time. Mean profile depth (MPD) was measured to assess the properties of surface macrotexture. The international roughness index (IRI) was measured to evaluate the surface smoothness. Data analysis was conducted to examine the effect of possible factors on the surface characteristics. Based on the results, the friction characteristics were identified and the typical MPD was determined. The improvement in surface smoothness from microsurfacing was assessed. It is believed that the original and reliable information presented herein can be utilized to better assess the performance of microsurfacing and perform engineering analysis.

Keywords
Microsurfacing, pavement friction, preservation, pavement roughness, rutting

1. Introduction

Microsurfacing is the application of a mixture of polymer modified asphalt emulsion, crushed and graded aggregate, mineral filler (commonly Portland cement to improve strength), water, and other additives, which have been properly proportioned and mixed, onto an existing HMA pavement. Microsurfacing is mainly utilized to correct rut and restore pavement friction. In many situations, however, microsurfacing can also be used to repair pavement surface damage such as weathering and raveling. While its mix is prepared and paved using a slurry seal machine, microsurfacing differs from slurry seal in that slurry seal uses a standard, conventional asphalt emulsion, but microsurfacing uses a polymer-modified asphalt emulsion. As a result, slurry seal requires more curing time (several hours) depending on the weather and pavement conditions for water evaporation and the asphalt emulsion to break and to be fully cured. Unlike a standard asphalt emulsion, a polymer-modified asphalt emulsion produces chemical action to drive water out, resulting in less curing time (usually less than one hour) and faster development of strength. Also, microsurfacing commonly uses higher quality aggregates.

On the one hand, microsurfacing uses nominal maximum aggregate size of 4.75-mm dense-graded fine aggregates, which allows an application as thin as 3/8 inch without compaction (Smith and Beatty, 1999). On the other hand, microsurfacing uses higher quality aggregates and polymer-modified asphalt emulsion and produces fast setting and greater strength, which allows thicker (up to 1 inch) application on high volume roadways to correct wheel path rutting that may exceeds ¾ inch and enhances long-term pavement surface friction performance. Particularly, the use of polymer modified asphalt emulsion can not only improve aggregate retention and enhance resistance to cracking and traffic wearing, but also reduce thermal susceptibility. The application of microsurfacing can be combined with other pavement preservation treatment such as chip seals to reduce aggregate loss, improve surface smoothness and provide desired pavement appearance. This paper presents the results of a study conducted to evaluate the field performance of microsurfacing, particularly the surface friction properties.

2. The Pilot Microsurfacing Projects

2.1 The Selected Test Sections

INDOT started to formally experiment with microsurfacing in 2007. Afterwards, several more microsurfacing projects have been completed for the purpose of field assessment. Presented in Table 1 is the information, including road, approximate length, traffic volume and construction completion date, on the six test sections that were selected for evaluating the surface characteristics of microsurfacing. All six test sections were located on two-lane highways. The test section on SR-3 was a resurfacing project running through the City of Rushville, consisting of 15 junctions with local town streets. The test section on SR-56 was 11.5 miles long, of which, one portion (about six miles long) was located outside of the City of Madison with an average annual daily traffic (AADT) of 2,267 and an average daily truck of 246, and the remaining portion was located inside the City of Madison with an AADT of 10,320 and an average daily truck traffic of 679. The greatest AADT of 15,596 was observed on SR-22 and the greatest truck traffic of 1,501 was observed on SR-3. The table shows that the six test sections covered a wide range of AADT on non-interstate highways.

Table 1: Microsurfacing Test Sections

Road	Length	AADT (2007)	Truck	Completion
SR-22	1.0 mi.	15,596	500	09/2007
SR-3	0.7 mi.	11,837	1,501	10/2007
SR-28	0.4 mi.	6,578	732	09/2007
SR-70	9.3 mi.	1,744	206	08/2008
SR-56	11.5 mi.	2,267/10,320	246/679	09/2008
SR-227	7.0 mi.	1,964	77	09/2009

2.2 Requirements for Microsurfacing Mixes

The polymer modified asphalt emulsion specified by INDOT is a quick-set, CSS-1H emulsion. The minimum polymer solids content is 3.0% based on the residual of the emulsion. Special additives are required to provide control of the quick-set properties. The coarse aggregates of Class B or higher is required for microsurfacing mixes. For rut filling, the required coarse aggregates include limestone, dolomite, crushed gravel, sandstone, steel furnace (SF) slag or Air Cooled Blast Furnace (ACBF) slag. The fine aggregates for microsurfacing are the same as those for HMA surface mixes, including limestone, dolomite, crushed gravel, sandstone, SF, ACBF or Polish resistant aggregate. When used for leveling application, the selection of fine aggregate type is based on the equivalent single axle load (ESAL) category. Summarized in Table 2 are the main quality requirements for both coarse and fine aggregates for microsurfacing. Table 3 shows the requirements for aggregate gradations used in microsurfacing, including leveling and rut filling applications. Portland cement of Type I is required to be used as the mineral filler. The detailed information on the quality requirements for microsurfacing materials can be found in the INDOT Standard Specifications (INDOT, 2010).

Table 2: Specifications for Microsurfacing Aggregates Properties

Requirements	Coarse Aggregate	Fine Aggregate
Aggregate Class	B or Higher	-
Los Angeles Abrasion, %, Max.	40	-
Freeze and Thaw Soundness, %, Max.	12	10
Sodium Sulfate Soundness, %, Max.	12	10
Brine Freeze and Thaw, %, Max.	30	12
Crushed Particles, %m Min.	70	-
Aggregate Angularity, %, Min.	95	45
Sand Equivalency, %, Min.	-	60

Table 3: Specifications for Microsurfacing Aggregate Gradation

Sieve Size (mm)	Leveling	Rut Filling
9.5	100	100
4.75	85-100	70-90
2.36	50-80	45-70
1.18	40-65	28-50
0.6	25-45	19-34
0.3	13-25	12-25
0.15	7-18	7-18
0.075	5-15	5-15

3. Surface Friction Characteristics

3.1 Friction on Freshly Placed Surface

A freshly placed microsurfacing can be opened to traffic after adequate cohesion has been developed to resist traffic abrasion. This usually occurs when the microsurfacing surface has turned black (Caltrans, 2003). Rolling with pneumatic rollers is not necessary but may be utilized to reduce aggregate loss. Presented in Figure 1 are the friction numbers measured on four of the six test sections right after opening to traffic. Two main observations can be made in Figure 1. First, it is apparent that the freshly placed microsurfacing pavements in the test sections produced sufficient surface friction. The lowest friction number was 28 on SR-22 westbound and the greatest friction number was 57 on SR-56 eastbound. Figure 2 shows a photo of a fresh microsurfacing pavement. While the surface was wet, the surface friction was sufficient to withstand traffic when opening to traffic. Second, the surface friction on the freshly place microsurfacing pavement varied significantly from test section to test section. This is probably due to the effect of curing process. The state of curing not only affects the development of mix strength, but also affects the surface properties. In reality, it has been pointed out that a microsurfacing pavement will not lose all water in the first hours after placement (Caltrans, 2003). It may take up to several weeks for the total water loss process to end, depending on the weather and existing pavement conditions. While the placement of the microsurfacing in one direction is always earlier than that in the other direction, the friction numbers on the freshly placed microsurfacing were very consistent in both directions in each test section. Therefore, a freshly placed microsurfacing pavement can not only provide sufficient surface friction, but also produce consistent surface properties and early opening to traffic. This confirms the benefits to use polymer in microsurfacing application.

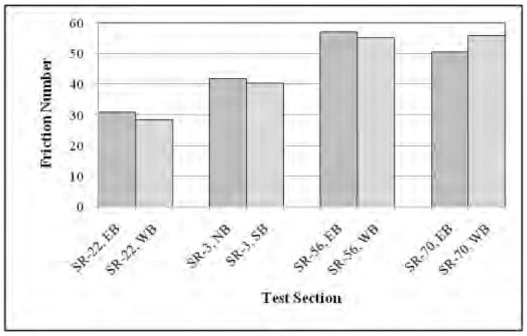


Figure 1: Friction Numbers on Freshly Placed Microsurfacing Pavements

Figure 2: Photo of a Fresh Microsurfacing Pavement

3.2 Friction Variation over Time

As curing proceeds, the strength of microsurfacing mix develops and the asphalt emulsion on the surface dries out. Presented in Figure 3 are the friction numbers measured in five of the six test sections over time. No friction variation was measured on SR-3. As mentioned earlier, this section consists of 15 junctions. It was very hard to conduct locked wheel friction testing without traffic control. In addition, some data such as the data on SR-22 after 12 months of service and on SR-56 after 18 months of service, is not available because the research team was unable to conduct testing due to other on-going major road works. As illustrated in Figure 3, the surface friction of microsurfscing pavement increased significantly in the first six months, and reached the maximum number approximately after 12 months of service. This indicates that the surface of a typical microsurfacing pavement may become stable and produce true friction numbers after 12 months of service.

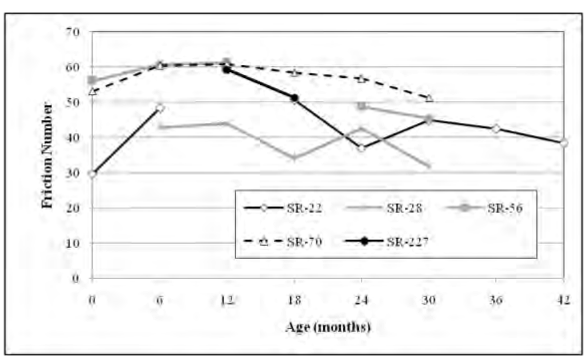


Figure 3: Friction Variations on Microsurfacing Pavements Over Time

Afterwards, the surface friction number decreased over time. Traffic volume had an impact on the variation of surface friction. The surface friction in the test sections with high traffic volumes, particularly truck traffic, decreased more than that with light traffic volume. Also, it appears that the surface friction in the microsurfacing pavements has always decreased after 12 months of service and tended to decrease faster over time. However, no friction number less than 30 occurred in all of the five test sections. A microsurfacing pavement commonly uses a 4.75-mm dense-graded fine aggregate mix. In reality, the aggregate gradation for the microsurfacing leveling mix is very similar to that for a conventional 4.75-mm HMA dense-graded fine aggregate mix. However, the use of polymer modified asphalt emulsion and special additives provides the microsurfacing mix enhanced properties.

4. Surface Macrotexture and Smoothness Characteristics

4.1 Surface Macrotexture

Illustrated in Figure 4 are the close-up views of the microsurfacing pavements in two test sections. The surface on SR-227 demonstrated aggregate particles protruding from the surface. The surface on SR-70 demonstrated angular aggregate particles. Both surfaces produced coarse textures. Texture testing was conducted to measure surface macrotexture profiles and associated mean profile depth (MPD) using a laser scanner (AMES Engineering, 2006 a). The reason for using such a device was that it would reduce testing time tremendously and minimizes the need for traffic control. Presented in Table 4 are the MPD values of surface macrotexture measured in the right wheel path in these five test sections. The greatest MPD was 0.951 mm that measured on SR-70. The lowest MPD was 0.366 mm that was witnessed on SR-22. In general, it looks that most measured MPD values were greater than 0.60 mm. When compared to the macrotexture depths of HMA pavements (Li et al. 2012), the microsurfacing pavements in these test sections produced surface properties much better than those on conventional 4.75-mm dense-graded HMA pavements and equivalent to those on 9.5-mm HMA pavements.

Table 4: Macrotexture Measurements

Test Section	Pavement Age	AADT/Trucks	MPD (mm)
SR-22	42 months	15,596/500	0.366-0.447
SR-28	30 months	6,578/732	0.779-0.934
SR-56	30 months	2,267 (10,320)/246 (679)	0.661-0.649
SR-70	30 months	1,744/206	0.665-0.951
SR-227	18 months	1,964/77	0.648-0.683

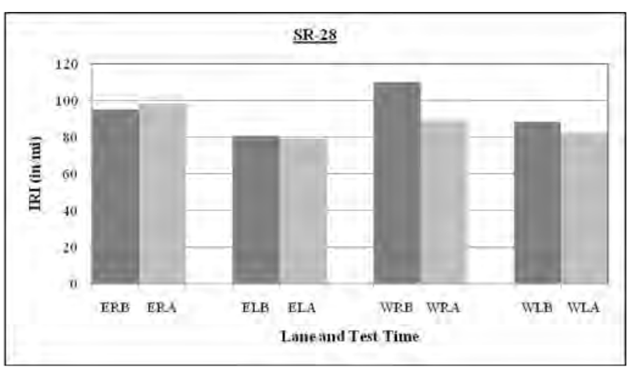
(a) SR-227 (b) SR-70

Figure 4: Close-Up Views of Microsurfacing Pavement Surfaces

A typical microsurfacing mix commonly uses dense-graded fine aggregates with a nominal maximum aggregate size of 4.75-mm. Particularly the aggregate gradation for the microsurfacing leveling is close to the aggregate gradation for a conventional 4.75-mm dense-graded fine aggregate mix. The reason that microsurfacing produces better surface macrotexture properties than a 4.75-mm HMA dense-graded pavement is not fully understood at this time. To the authors' knowledge, the strength mechanism for a microsurfacing mix is different from that for a conventional HMA mix. For microsurfacing mixes, the rheological properties of asphalt emulsion residue improve significantly due to the use of polymer and special additives. The microscopic honeycomb structure of flexible cement-polymer formed in a microsurfacing mix plays a critical role in early strength and rutting resistance (Takamura, 2001). Li et al. (2005) observed that HMA surfaces with rutting issues tended to experience low friction performance in the long term. Also, the polymers adhering to the aggregate surface may also have improved the properties of pavement surface texture.

4.2 Surface Smoothness

Field testing was conducted to measure surface longitudinal profiles (ASTM, 2018) using an inertial profiler system (AMES Engineering, 2006 b) and the international roughness index (IRI) (ASTM, 2003) was computed to assess the smoothness of the surface in each test sections. During testing, the longitudinal profiles were measured in both the right and left wheel paths in each direction. Figure 5 shows the IRI values measured before and after placing microsurfacing in three test sections located on SR-28, SR-70, and SR-227. In the figure, the three-letter symbols represent the direction of road, the wheel path, and the testing time. As an illustration, ERB denotes eastbound, right wheel path, and before microsurfacing. On the freshly placed microsurfacing, the surface smoothness varied between right and left wheel paths and between different directions. The IRI increased in two situations, one in the right wheel path on SR-28 eastbound and the other in the right wheel path on SR-227 northbound. However, the surface smoothness improved in most situations after placing microsurfacing. The greatest improvement occurred on SR-70 westbound with a decrease in IRI by 26%. Table 5 shows the IRI measurements made right after opening to traffic and in 2011. The test section on SR-28 experienced the greatest change in smoothness and the IRI increased by approximately 9 points each year. IRI increased by 1 to 6 points each year in other test sections. The IRI increased in proportion to traffic volume.



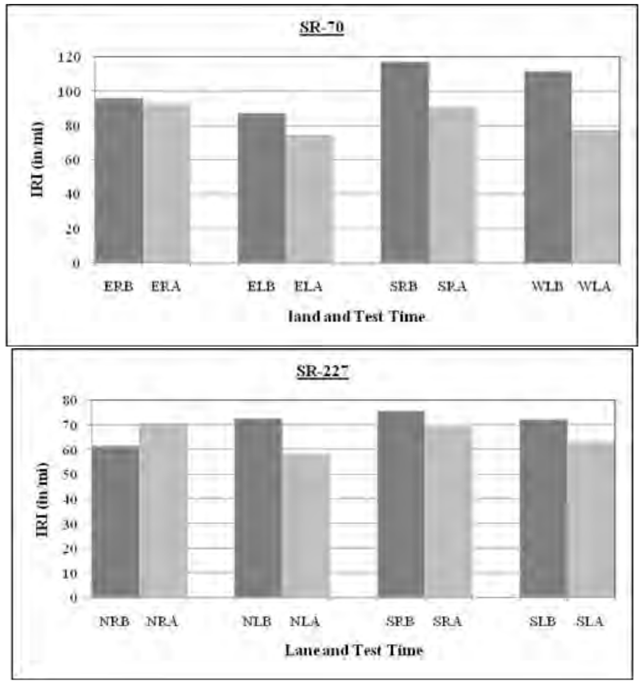


Figure 5: IRI Values in Three Test Sections

Table 5: IRI Variations over Time in Four Test Sections

Road	Direction	Months in Service	IRI on New Microsurfacing	IRI in 2011	IRI Decrease (%)
SR28	East	42	88.8	121.4	36.8
	West	42	85.8	116.2	35.4
SR56	East	30	60.4	73.8	22.2
	West	30	69.9	76.9	10.1
SR70	East	30	83.5	91.4	9.5
	West	30	84.0	86.6	3.1
SR227	North	18	64.1	71.2	11.0
	South	18	66.1	75.1	13.5

The above observations indicate that the smooth improvement from microsurfacing depended to some extent on the smoothness of existing pavement. The rougher the existing pavement surface the greater the smoothness improvement after placing microsurfacing. However, the effectiveness of microsurfacing in enhancing surface smoothness was limited, particularly when the smoothness of existing pavement was in good condition. This may be due to that microsurfacing in Indiana was commonly placed in two courses, including leveling and surface course. The thickness of microsurfacing was ultrathin, around 3/8" (9.5 mm). In addition, the application of microsurfacing was accomplished without compaction, which might also affect surface smoothness. It is also indicated that the surface smoothness in the left wheel path was always better than that in the right wheel path after applying microsurfacing.

5. Conclusions

Microsurfacing has been recognized as an effective treatment in pavement surface preservation. Based on the test data and analysis results from the study presented in this paper, the main conclusions can be reached as follows:

- Freshly placed microsurfacing could produce sufficient and consistent surface friction to withstand traffic and allow early opening to traffic. The friction numbers varied between 28 and 57 on freshly placed microsurfacing.
- The surface friction of microsurfscing pavement increased significantly in the first six months and reached the maximum number after 12 months of service. In other words, the microsurfacing pavements produced stable surface and true friction numbers after 12 months of service. Afterwards, the surface friction number decreased over time. However, no friction number less than 30 occurred in the test sections. Traffic volume had an impact on the variation of surface friction.
- The typical MPD was commonly greater than 0.60 mm. For microsurfacing mixes, the use of polymer and special additives may play a critical role in producing and maintaining good friction performance.
- The smooth improvement from microsurfacing depended to some extent on the smoothness of existing pavement. The rougher the existing pavement surface the greater the smoothness improvement after placing microsurfacing. However, the effectiveness of microsurfacing in enhancing surface smoothness was limited when the smoothness of existing pavement was in good situation. The surface smoothness in the left wheel path was always better than that in the right wheel path.

Acknowledgments

This research project was sponsored by INDOT in cooperation with the Federal Highway Administration through the Joint Transportation Research Program (JTRP). The authors would like to thank David Andrewski, Mike Prather, Jeffrey James, Jewell Stone, Shakeel Baig, and Tom Duncan for their guidance. Sincere thanks are extended to Mark Leichty for providing the laser scanner. The assistance from Tony Jonson, Kyle Long, and Patrick Weaver is also acknowledged. The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of INDOT. This paper does not constitute a standard, specification, or regulation.

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Remoteness, Mental Health and Safety Behaviour among Oil and Gas Workers

Anwar S. Alroomi
Griffith University, Gold Coast, Australia, anwar.alroomi@griffithuni.edu.au

Sherif Mohamed
Griffith University, Gold Coast, Australia, s.mohamed@griffith.edu.au

Abstract
The literature lacks a model that combines working in remote and isolated areas, safety behaviour and the relationship between them. This paper reports on an ongoing research study investigating the influence of remoteness on workers' mental health and, in turn, on their safety behaviour. The paper presents a conceptual framework comprising a number of dependent and independent variables for remoteness identified through the literature (i.e., physical isolation and occupational stressors) and for safety behaviour (i.e., compliance and participation). The framework (and relevant hypotheses) is intended to examine the mediating role workers' mental health can have on the remoteness–safety behaviour relationship. Mental health is represented by two more variables; namely, anxiety and depression. This paper is theoretical in nature, focuses on oil and gas workers working in remote areas, but its content should be relevant to the construction industry where the use of a non-resident workforce is common practice in many parts of the world, especially in the Middle East—the geographic focus of this study.

Keywords
Safety behaviour, mental health, occupational stressors, social isolation, loneliness.

1. Introduction

Work in the oil and gas industry presents dangers and challenges, as it is usually undertaken in remote locations and difficult geographical environments. Occupational hazards and the potential for accidents are frequently linked to fatigue and stress-related risk factors (Chan, 2011). Mental health is a significant issue for oil and gas workers, especially those offshore, because of the issue of site/field remoteness. The offshore environment is potentially stressful because the workforce lives and works in one restricted location for a significant time. Life offshore has been described as dangerous, arduous and socially isolating (Wong et al., 2002). The health and safety of workers are affected adversely by the special challenges of offshore work, together with its restrictions, which include isolation from family and community (Chen et al., 2003).

Remoteness is a central concept in this study and is defined as physical isolation, combined with the condition of being a worker in isolation from one's family, friends and familiar surroundings. Such physical isolation is also related to a challenging environment, which is taken into account when assessing the effect of remoteness. Most oil and gas projects are located away from major cities, with a low level of services and infrastructure available—conditions that are typical of the industry in general. Workers reside in camps just beside their workplaces and might be exposed to severe weather hazards.

Many studies have been conducted into the occupational stress influencing offshore workers (Chen et al., 2009; Cooper and Sutherland, 1987; Parkes, 1992). Cooper and Sutherland (1987) identified some of these occupational stressors as risk factors for decreased overall well-being, free-floating anxiety, depression and somatic anxiety. Further, Chen et al. (2009) claimed that some sources of occupational stresses had a positive association with poor mental health. Also, certain other studies have indicated that occupational stress can predict mental health (Chen et al., 2001; Cooper et al., 1989; Lu et al., 1997).

This paper aims to review the relevant literature and proposes a conceptual framework to be empirically tested using a sample of foreign workers in the oil and gas industry in Kuwait. In other words, this study aims to investigate the relationship between working in remote areas and the safety behaviour of workers, directly and indirectly, through their mental health status. Kuwait was selected for the current study because the oil and gas industry is the largest industry in the country, accounting nearly half of the country's gross domestic product. To the authors' best knowledge, no prior study has been conducted in Kuwait (or any of the Gulf Countries) on the effect of remoteness on workers' mental health and safety behaviour. In Kuwait, foreign workers in the oil and gas industry come from diverse countries within Asia and are relocated to a remote, isolated and totally new geographical region. Isolation periods vary from weeks to months, and are usually far longer than any periods reported by previous studies on this topic. Figure 1 presents the conceptual model that captures the scope of the study graphically.

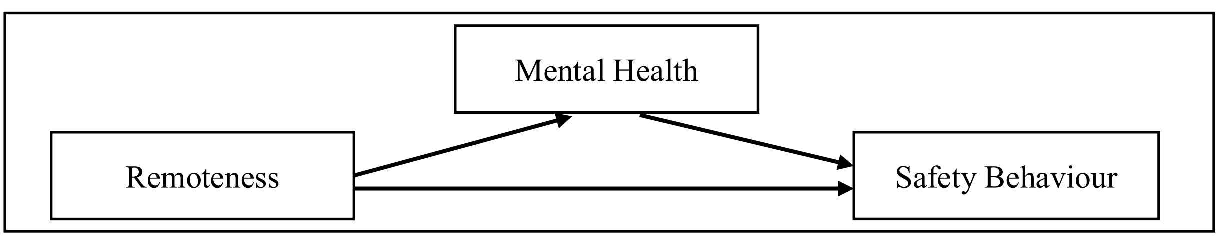

Figure 1: Preliminary Conceptual Model

2. Literature Review

2.1 Remoteness

Remoteness has number of definitions, and there is no single universally recognised definition. In Australia, there are different classifications of remoteness depending on the issue being addressed or used. For example, Wakerman (2004) considers work in a remote area to be isolated geographically, socially and professionally. In Kuwait, oil platforms and oil rigs are located around the country, with most oil and gas projects away from major cities. The majority of oil and gas workers come from different parts of the world, and many foreign workers leave their home country to live in the field for extended periods of time. Workers therefore face some hardships. In this study, the remoteness variables are considered to be the independent variables, and have been divided into two constructs (physical isolation and occupational stressors), each with its own separate items necessary for construct operationalisation. Below is a brief description of each construct.

2.1.1 Physical isolation

A review by *The Age UK* concluded that feeling lonely is most closely linked to the single variable of physical isolation (The Age, 2010). Furthermore, the House of Representatives Standing Committee on Regional Australia (HRSCRA) (2013) stated that frequent separation from family support and social isolation, informal social controls and the absence of a sense of community can have negative consequences on fly-in–fly-out (FIFO) workers' well-being. Similarly, physical isolation can also be identified from studies that have been conducted on university students and migrants who arrive in an environment that is somehow different and consequently feel physically isolated. According to De Jong Gierveld and Van Tilburg (2006) young people (e.g., students) who have moved to places where they are newcomers frequently report loneliness as a consequence of social isolation. In this paper, the effects of being physically isolated will be measured objectively (in terms of social isolation) and subjectively (as loneliness).

The paper adopts the definition of social isolation from Shankar et al. (2011) as an objective, quantitative measure of network size and diversity as well as frequency of contact. The definition of loneliness was adopted from Cacioppo and Patrick (2008) who describe it as a debilitating psychological condition typified by emptiness, isolation, a sense of worthlessness and lack of control as well as vigilance against external personal threat. Furthermore, a definition from an interesting study by Wright (2005) of loneliness in the workplace been added to this study to make sure that loneliness in the workplace is included as well. Loneliness in the workplace is defined as the distress arising from a perceived lack of high quality interpersonal relationships between employees at work.

2.1.2 Occupational stressors

Occupational stress is defined as the inability of the individual worker to cope effectively with various work demands (Blix et al., 1994). Oil and gas workers are frequently exposed to stressful conditions or physical pressures. Long-term employment in an isolated location also contributes to occupational stress levels (Brešić et al., 2007).

Occupational stressors in the oil and gas industry were investigated by Cooper and Sutherland (1987), who identified seven sources of occupational stress affecting North Sea offshore oil workers: 'relationships at work and at home', 'site management problems', 'factors intrinsic to the job', 'the uncertainty element of the work environment', 'living in the environment', 'safety' and 'interface between job and family'. Later, in their study of 561 Chinese offshore oil workers Chen et al. (2001) ascertained nine factors of occupational stress: 'interface between job and family', 'career and achievement', 'safety', 'management problems and relationships with others at work' (which they subsumed under one label), 'physical environment of the workplace', 'living environment', 'managerial role', 'ergonomics' and 'organisational structure'. When analysing all the stressors from these two studies, it is clear that ‘living environment’, ‘interface between job and family’ and ‘relationships at work and at home’ are more related to this study’s concept of remoteness than the others are. In this paper, the last two stressors were combined into a single variable, ‘responsibilities towards family’. These stressors are therefore worthy of investigation to identify their effects on mental health, fatigue and safety; and thus the occupational stressors examined in this study are ‘responsibilities towards family’ and ‘living environment’.

2.2 Safety Behaviour

Safety behaviour in this research represents the dependent variable and is a well-recognised concept in the safety literature. It is defined as an individual’s behaviour to enhance their own health and safety and that of their working environment (Burke et al., 2002). Neal et al. (2000) conceptually distinguished two components of such behaviour that can be used for describing workers’ actual behaviour on site: safety compliance and safety participation. These categories have received broad acceptance in research and in practice.

Safety compliance is defined as the core safety activities required for individuals to sustain workplace safety, whereas safety participation is conceptualised as behaviours that might not directly contribute to workplace safety, but assist in fostering a climate promoting safety (e.g., participating in training and voluntary safety meetings).

2.3 Mental Health

Mental health is a mediating variable in this research. It has long been described as the absence of psychopathology (Lamers et al., 2011). The World Health Organization (WHO) defines it as ‘a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community’ (WHO, 2004, p. 12).

In the workplace, it is vital to consider the effect of mental health issues on the quality of life of workers and their families as well as on workers’ physical health and work-related performance (Kim et al., 2009). Studies reveal that working in an intense and pressured work environment can lead to psychosocial problems, including sleep disorders, stress, anxiety and depression (Love et al., 2009).

Depression and anxiety are the most frequently occurring mental disorders that affect working-age adults. Their prevalence seems to be on the rise in Western societies (Reichenberg and MacCabe, 2007). Hence, depression and anxiety are the two mental health disorders of interest in this study.

2.5 Variables and Constructs: Relationships

2.5.1 Remoteness variables—safety behaviour relationship

Many studies have examined the relationships between remoteness variables impacting or influencing safety, and most are qualitative in nature. Separation from family and one’s community and living in camps were potential stress-related factors in migrant Chinese workers in China, where these factors could be a risk for safety or affect safety (Chan, 2009). Siu (2001) argued that emotional overload, the result of factors such as being away from family, predicts accidents.

Finally, stress at work can reduce safety and increase the chance of occupational injury for workers on oil platforms (Parkes, 1992). The first hypothesis in this research is, therefore:

H1. Remoteness variables are negatively associated with safety behaviour.

2.5.2 Mental health is a mediating variable

2.5.2.1 Physical isolation—mental health relationships

A recent editorial in the *American Journal of Public Health* underlined the importance of social isolation as a threat to good mental health (Klinenberg, 2016). Being socially isolated has negative consequences on mental health, as reported in various studies (Cornwell and Waite, 2009; Coyle and Dugan, 2012). Hall-Lande et al. (2007), who investigated young people, revealed that social isolation was linked with an accelerated risk of depressive symptoms, suicide attempts and low self-esteem. It may place individuals at increased risk for poor mental health (Hawton et al., 2011). Evidence suggests that interventions to increase social interactions can actually decrease depressive symptoms (Cattan et al., 2005).

Similarly, many studies have further demonstrated that loneliness is a risk factor for depression (Cohen-Mansfield and Parpura-Gill, 2007; VanderWeele et al., 2011). Loneliness can be injurious to one's health; in particular, to one's mental health (Wilson et al., 2007). Ernst and Cacioppo (2000) identified that extended loneliness increases the risk of depression and even suicide. Hagerty and Williams (1999) found a significant association between loneliness and symptoms of depression in both undergraduates and patients with a major depressive disorder.

2.5.2.2 Occupational stressors—mental health relationships

As indicated earlier, two occupational stressors namely 'responsibilities towards family' and 'living environment' have been selected in this study. In the context of the former stressor, Cooper and Sutherland (1987) revealed that stress in relationships at work and at home is a risk factor for decreased overall well-being, free-floating anxiety, depression and somatic anxiety. Based on Chen et al. (2009), the stress interface between job and family pressures has a positive association with poor mental health. The living environment—another occupational stressor—is a risk factor for decreased overall well-being, free-floating anxiety and phobic anxiety, due to the requirements of shared living and sleeping quarters and the consequent lack of privacy and disturbance by others (Cooper and Sutherland, 1987).

2.5.2.3 Safety behaviour—mental health relationships

Anxiety and depression are two of the major common mental health disorders. One study (Haslam et al., 2005) on the effects of anxiety and depression and of their treatment on performance and safety in the workplace revealed an association with impaired work performance and safety for workers with anxiety and depression, either treated or not currently treated. Another study (Murray et al., 1997) demonstrated that fishermen reported high levels of anxiety, with those who reported most anxiety also reporting more injuries and fewer safety precautions. In the oil and gas industry, Parkes (1992) identified that an offshore environment increases the anxiety of workers compared with an onshore one. Beseler and Stallones (2013) examined the pattern of associations between pesticide poisoning, depressive symptoms, safety knowledge, safety behaviours and injury for farm operators and their spouses. They concluded that depression is more strongly associated with safety behaviour than safety knowledge is. In China, Zheng et al. (2010) found a link between depressive symptoms and greater risk of work-related injuries in male Chinese construction workers. In an investigation of the safety climate among construction workers in Hong Kong (Siu et al., 2004), psychological distress (depression and anxiety) levels were found to predict accident rates, with direct mediating effects on accident rates and a negative relation with safety attitudes. From this section, two more hypotheses can be formulated for testing:

H2. Remoteness variables are positively associated with mental health.

H3. Mental health is negatively associated with safety behaviour.

Figure 2 represents the conceptual model and the associated hypotheses.

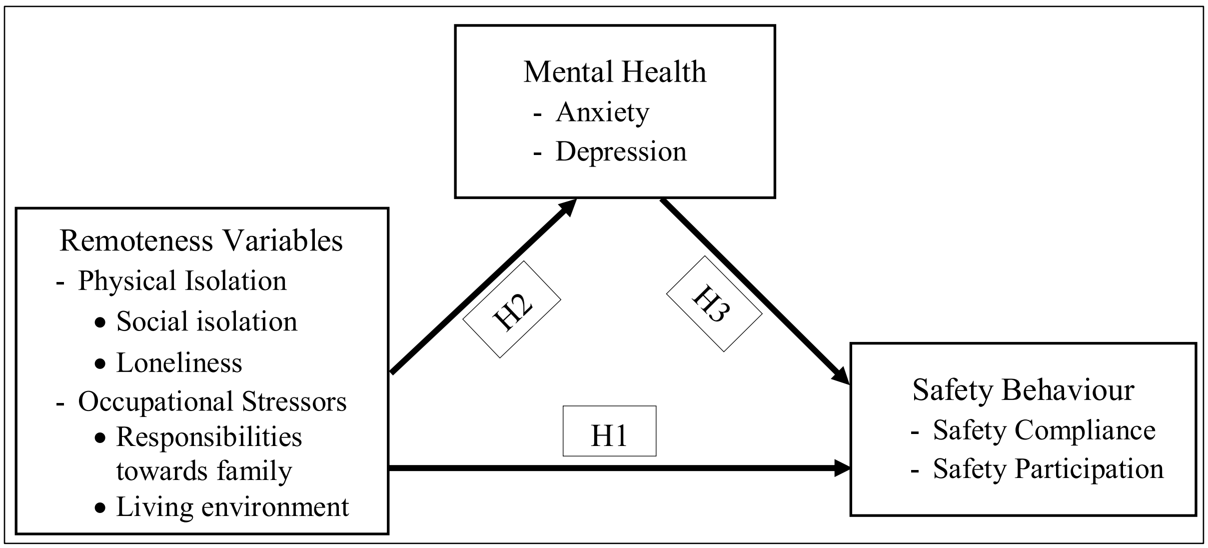

Figure 2: Conceptual Model

3. Research Methodology

The purpose of this study is to empirically test the proposed hypotheses about the influence of remoteness variables on workers' mental health and safety behaviour. It will also examine the mediating role of mental health between remoteness and safety behaviour. Since the purpose of the study is to empirically assess the relationships between different constructs, with a view to generalising the findings to the target population, quantitative methods are deemed to be more appropriate than qualitative ones. The research design judged to be the most appropriate for this purpose is the survey design. The survey method is more effective for showing correlations between constructs, and for generalising from a sample to target population. A questionnaire will be developed using the literature review and distributed to a representative sample of foreign workers in Kuwait in order to collect the data necessary to test the three hypotheses.

4. Discussion and Relevance to Construction

The use of a non-resident workforce is not confined to the oil and gas industry. This practice has been an integral part of many construction operations in many parts of the world, especially in the Middle East. Unfortunately, very few studies are available addressing the influence of remoteness on safety behaviour. In Australia, as a result of the rapid expansion of the resources sectors, many companies rely on FIFO work arrangements, which can be defined as involving workers whose permanent place of residence is beyond daily commuting range of their work site. This practice is quite common in other parts of the world, particularly for large-scale infrastructure projects. On examining this practice in Western Australia, Mckenzie et al. (2014) reported that if offers many challenges for workers and their families: extended separation, potential for loneliness and isolation; and disruption to previous work-life balance patterns. This was supported by another study (Barclay et al., 2016) where experiences of loneliness and social isolation were reported to be common among FIFO geologists. Irrespective of employment roles or education levels, the core demands of FIFO employment involve isolation, sleep problems and loneliness having detrimental effects on workers' well-being, and all of these can lead to safety concerns (Biggs et al., 2016).

Research scholars are of the view that construction organisations that successfully provide safe working environments are those that outperform their competitors. Yet, researchers suggest that because of the complex nature of evaluating mental health, and its link to emotional and cognitive behaviours, more empirical studies on the relationship between mental health and safety behaviour are needed (Biggs et al., 2016). This suggestion partly underlies the motivation for this study.

In light of the above, the similarity of remoteness between the construction and oil and gas industries is clear. This similarity can be further complicated when considering that in countries across the Middle East, the majority of construction workers are non-residents and can face language, social and cultural barriers. It is only recently that the welfare of overseas workers in the Middle East has become a frequent focus of attention in the media. This will ensure that our future study findings, based on the empirical testing of the conceptual framework and its relevant hypotheses, are relevant to construction companies seeking to enhance workers' safety behaviour in remote areas and in harsh environments.

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Quantity Uncertainties in Shuttering Works – Comparison of Public versus Private Clients

Markus Kummer
(Project Assistant, Graz University of Technology, Graz, Styria, Austria)

Abstract
Uncertainties are systematically considered and dealt with by applying probabilistic calculation methods, such as Monte Carlo simulations. When selecting appropriate distribution functions for input parameters, users are constantly faced with the issue of having to choose the "right" distribution function for the relevant parameter. Quantities of individual works play a crucial role for costing and pricing, but also for construction process and logistics planning purposes. Quantities stated by the client in its structural specifications are fraught with uncertainties owing to, for instance, incomplete plans at the time of specification, inaccurate calculations, or mere estimates. This is why actual quantities can either be greater or smaller than the specified quantities.
From the point of view of the bidder/contractor, the above-mentioned quantity uncertainties constitute a risk (for instance with respect to the contribution margin), but also a chance (such as in unit-priced contracts in the case of quantity increases at a high unit price), and should be reflected by distribution functions of relevant quantities in the probabilistic costing exercise. Considering quantity uncertainties is also of interest to clients in order to investigate, during the phase of selecting the best bidder, how prices quoted by bidders would move when specified quantities change in the case of unit-priced contracts.
This paper demonstrates how distribution functions can be derived from expert surveys delivering responses from actual construction practice. Specific reference is made to shuttering works whilst distinguishing between public and private clients. The outcomes of the survey presented and discussed in this paper include descriptive data analyses as well as violin plots and fitted distribution functions.

Keywords
Distribution functions; expert survey; data fitting; management of chances and risks; quantity uncertainties; Monte Carlo simulation; uncertainty

1. Introduction

Any probabilistic calculation requires the selection of distribution functions for uncertain input parameters. When trying to choose the "right" distribution, users are constantly confronted with the issue of which of the many available theoretical (mathematically described) distributions would best reflect the characteristics of the relevant parameter. After selection of the type or kind of distribution, the corresponding shape parameters must be defined to be able to perform a Monte Carlo simulation.

Three methods and their combinations are generally available for selecting distribution functions: (Kummer, 2015)

- theoretical considerations based on known or assumed characteristics
- gathering data from construction practice
- expert surveys

In this context, theoretical considerations refer to the basic characteristics of the relevant distribution function, such as discrete vs. continuous, open vs. closed boundaries, mode, and skewness. The second basis for selecting an appropriate distribution function is to gather data directly from construction practice. In this case, an additional distinction is made between historical data (*ex post* – after the construction phase, for instance information taken from final costing or daily work reports) and data collected during the construction phase (*inter actio* – such as from direct site observations). When continuously gathering data during the construction phase, appropriate boundaries or limits must be defined in terms of space, time, and content, and the quality of the data must be ensured. Furthermore, collected data must be assessed, prior to analysis, to find out if data can be applied directly or if there is any need for fitting or adjustment. Only if data has been put in, or linked to, the appropriate context can information be generated from it for the purpose of making this data usable for additional analyses and calculations. Another key criterion that determines data quality is the number of data points, or number of observations. The smaller the sample and the greater the standard deviation of gathered data, the greater the inaccuracy of the derived estimation of the parameters of the underlying population.

AbouRizk/Halpin (1992) state that it is not possible to categorize distributions on the basis of fewer than 20 observations. It should be noted, though, that 20 responses taken from expert surveys provide a higher quality of information than 20 data points taken from observations, which, for instance, can be extracted from various projects using related logs and records. This principle holds true particularly if special emphasis is placed on the selection of appropriate experts, the drafting and preparation of a standardized questionnaire, and the discussion of answers with respondents (similar to the Delphi method).

For the purpose of this research, expert surveys (*ex ante* surveys) were used to determine distribution functions for quantity deviations. Our preference for expert responses over individual measurements taken from construction practice is based on the fact that any expert statement already incorporates experiential evidence from several past projects. Moreover, respondents are capable of linking objective data to (known) complex contextual conditions in construction practice as well as to heuristics, which adds value to their responses. Any identification of quantity deviations between specification and invoicing will also involve the issue of defining appropriate boundaries with respect to contract addenda and/or cancelled works.

2. Expert Survey

It is usually impossible to interview all experts in a given field, with the exception of a few, highly specialized disciplines. This is why sampling is necessary to arrive at conclusions as to the underlying population on the basis of received responses. The selection of such experts relies on fundamental questions such as: Who is in possession of relevant information? Which of these experts are available? Whose willingness to provide information is the highest? Who is most likely in a position to provide accurate information? (Gorden, 1969)

In this context, experts are defined as individuals who possess specific knowledge and intellectual skills and competencies in a clearly delineated field and who serve as a source of specific knowledge for the purpose of a survey. Expert knowledge usually comprises exceedingly large amounts of information, including simplifications, lesser-known facts, rules of thumb, and smart practices (i.e., heuristics) that enable efficient problem solving (Gläser and Laudel, 2010; Springer Gabler, 2014). In a preselection process, a total of about 130 experts from Austria and Germany with experience in the fields of costing, process planning, construction, final costing, and invoicing were contacted in writing and asked to participate in the survey. In total, 27 experts were recruited for the survey. They provided 23 responses with respect to quantity deviations in shuttering works.

The majority of respondents (i.e., approx. 63%) worked for large companies with more than 250 employees, about 26% worked for medium-sized businesses (50 to 249 employees), and about 11% came from small businesses (10 to 49 employees). In the survey presented in this paper, experts had an average professional experience of 17.7 years; this experience ranged from 5 to 41 years. Questions were designed and developed together with social researchers (i.e., sociologists) in several revision steps, applying the principles of simplicity, clarity, impartiality, and specificity. On average, each respondent was interviewed for about 45 minutes either on the phone or in a face-to-face session to overcome ambiguities, collect missing information, or obtain background information and justifications of responses (Kummer, 2015; Hofstadler and Kummer, 2017).

A standardized questionnaire is an appropriate tool for gathering quantitative data. Data fitting can be applied to quantitative expert responses to generate theoretical distribution functions, such as for quantity deviations. Only in exceptional cases will such functions correspond to the complete range of theoretical considerations and characteristics of the relevant calculation parameter. Thus, the results of data fitting with respect to practical application must be combined with theoretical considerations and characteristics to define the shapes or curves of distributions.

3. Data Fitting

The issue of which distribution functions to apply to individual calculation parameters essentially determines the quality of the output of a Monte Carlo simulation. There is no uniform answer to this question. In the literature, both considerations regarding the “nature” and potential characteristics of individual parameters and the incorporation of historical data and use of expert opinions are discussed.

The transfer of such data records (e.g. from *ex ante*, *ex post* or *inter actio* surveys or observations) into distribution functions that can be described on a theoretical level is referred to as “data fitting”. In this process, existing data is first analyzed graphically in histograms and then assessed using mathematical/statistical methods in order to identify the theoretical distribution function that best reflects existing data (i.e. with the smallest deviation). Since distributions need to be adjusted to project-specific circumstances or conditions, the shape or curve of distributions of uncertain calculation parameters is of greater interest than absolute values.

An expert survey is recommended as the method to select the underlying data because the *inter actio* and *ex post* gathering of data is likely to present definition and allocation problems in the course of data processing.

Data processing is followed by actual data fitting, which involves a comparison and check for consistency of adjusted data with theoretical distributions that can be described mathematically. This theoretical distribution can then either be applied directly to the uncertain input parameter, or the input is optimized for the fitted distribution. This optimization step provides the advantage that the boundaries of the distribution can be modified on the basis of theoretical considerations and characteristics, which significantly simplifies the input (of minimum and expected values, for example) for the user. Furthermore, optimization makes it possible to define a conversion scheme to scale and adjust the derived distribution function to individual/project-specific conditions (Hofstadler and Kummer, 2017).

Fitting aims to determine the parameters of a distribution function (displacement and shape parameters) in a numerical process so that the distribution reflects gathered raw data as accurately as possible.

4. Quantity Deviations in Shuttering Works – Results of an Expert Survey

An expert survey conducted by Kummer and Hofstadler at TU Graz in 2015/16 collected responses with respect to the magnitude of deviations from quantities stated in the specifications of shuttering works expected for public and private clients. No absolute quantities but percentage deviations from the specified quantity were requested, with the latter being defined as 100%. Experts determined the lower limit of quantity deviations (quantity reduction) by indicating a percentage value smaller than or equal to 100% and the upper limit (quantity increase) by indicating a percentage value greater than or equal to 100%. For instance, stating a lower limit of 80% would correspond to a 20% quantity reduction. Conversely, an upper limit of, for example, 115% would be equivalent to a 15% increase in the quantity during the construction phase. The survey was related to quantity deviations in shuttering works and made a distinction between public and private clients.

Data collection, processing and subsequent analysis had to conform to a high quality standard based on key quality criteria in empirical research that have a major influence on data relevance and plausibility, i.e. objectivity, reliability, and validity.

In the expert survey, 23 responses were received with respect to quantity deviations in shuttering works (see Table 1). The figures stated for public and private clients differed only to a minor extent, which permits the conclusion of a similar overall degree of accuracy of specifications for shuttering works. Differences were primarily found for extreme values (i.e. minimum and maximum values). A mean quantity reduction to up to about 93% was observed for shuttering works (see Table 1, line 2, cells B and D, and line 14, cells B and D). Owing to the bimodal curve, the mode of quantity reductions amounts to 90% and 95%, respectively, in relation to responses regarding private clients (each with six responses).

The greatest specified quantity reduction declines to 80% in the case of public and to 85% in the case of private clients (line 10). Thus, quantity reductions in shuttering works tend to be more considerable in projects specified by public clients. Experts justified this finding by the fact that public-client specifiers tend to include an additional buffer when specifying the quantities of items contained in structural specifications. If smaller quantities are realized in the actual construction phase, the negative difference of invoiced prices can be set off against any additional cost claims that the contractor submitted for other items. This makes it easier to stand one’s ground in discussions with the client because greater quantities stated in the bid usually tend to result in a bid price increase, which creates a certain leeway compared to invoicing that can be utilized for negotiations between representatives of the client and the contractors without having to modify the project funding model.

Mean expected quantity increases amount to 7 to 8% (see Table 1, line 2, cells C and E, and line 14, cells C and E). A slightly larger quantity increase should be assumed for public-sector clients relative to the mean values and robust M-estimators (according to Huber). This tendency is also confirmed when considering the maximum values stated for quantity increases. Experts stated a quantity increase of up to 25% for private clients, whereas this increase amounted to up to 40% for public clients (line 11). However, the mode is 100% for both public and private clients, which means that the majority of experts did not account for any potential for quantity overruns.

Moreover, the outcomes revealed that negative deviations were associated with a left-skewed distribution of responses, whereas positive deviations resulted in a right-skewed distribution of responses (see Table 1, line 13). Relative to the complete range of answers, we thus assume a “cluster” (i.e. comparatively large number) of responses near the 100% mark.

Table 1: Descriptive representation of data pertaining to quantity deviations in shuttering works

No.	Parameter	Shuttering – public clients		Shuttering – private clients	
		Negative deviation	Positive deviation	Negative deviation	Positive deviation
0	A	B	C	D	E
1	N	23	23	23	23
2	Mean	92.87	108.17	93.17	107.61
3	Standard error of mean	1.03	1.93	0.86	1.54
4	Standard deviation	4.96	9.26	4.11	7.37
5	Coefficient of variation	5.34 %	8.56 %	4.41 %	6.85 %
6	Median	93.00	105.00	95.00	107.00
7	Mean absolute deviation	3.00	5.00	3.00	6.00
8	Robust coefficient of variation	3.23%	4.76%	3.16%	5.61%
9	Mode	90.00	100.00	90,00 or 95,00	100.00
10	Minimum	80.00	100.00	85.00	100.00
11	Maximum	100.00	140.00	100.00	125.00
12	Spread	20.00	40.00	15.00	25.00
13	Skewness	-0.65	1.95	-0.16	0.76
14	M-estimator (H12)	93.18	107.01	93.25	106.91
15	Standard deviation (H12)	4.92	7.52	4.68	7.32
16	Robust coefficient of variation	5.28%	7.03%	5.01%	6.85%
17	Normal distribution (Shapiro-Wilk)	Yes	No	Yes	No

Fig. 1 shows the ranges of expert responses but also the violin plots relating to them. Violin plots are an extension to the known box plot representation. They combine the information of a density function (or of a smoothed histogram) with that of a box plot in a single diagram. Their advantage is that the graphical representation includes not only box plot information but also distribution characteristics. In the diagram, the density curve is plotted symmetrically above and below the (vertical) box plot. The two halves of the violin plot differ only in the direction in which density is plotted. They are thus mirrored along the axis on which the relevant parameter is shown. This symmetrical representation facilitates interpretation and comparison of several distributions plotted adjacent to each other.

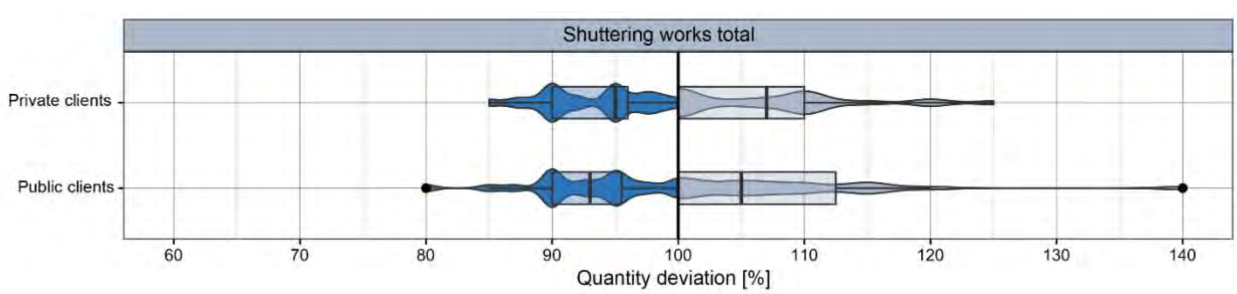
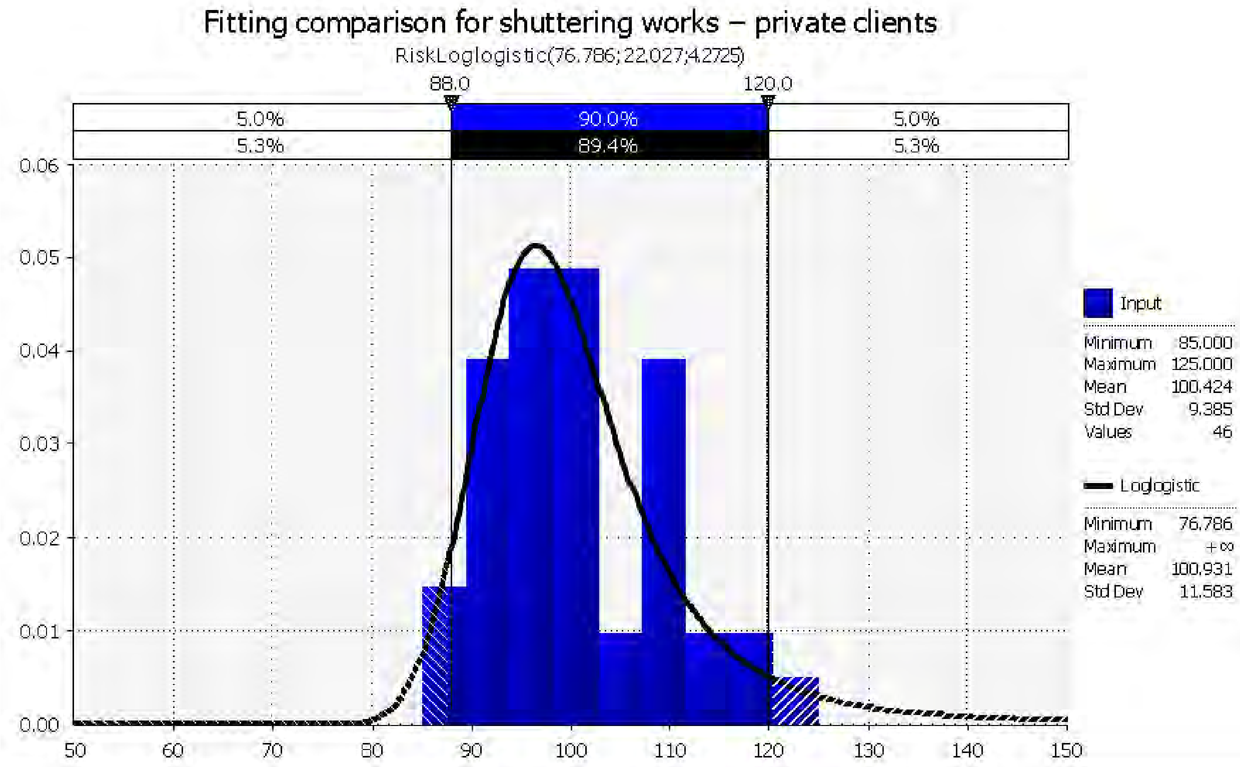


Figure 1: Violin plots of quantity deviations – shuttering works – public vs. private clients

Another benefit of violin plots is that the shape of the distribution or the presence of any accumulations or clusters within certain value ranges are easier to visualize. This type of information can get lost in conventional box plots. The greater the frequency of tapered zones in the violin plot, the larger the likelihood of a greater frequency of expert responses within certain value ranges. For instance, responses got clustered at quantity reductions of 90% and 95% in relation to shuttering works both for public and private clients. Between these two percentages, the violin plot exhibits only a small width, which permits the conclusion that fewer responses lie within this range. If no responses exist within a defined value range, the associated area of the violin plot reduces to zero and appears as a line (see, for example, quantity increase in shuttering works – public clients – near the 130% mark). Fig. 1 uses circles/dots for outliers (there are no extremes in this case). The number of responses cannot be derived directly from the violin plot, which is why descriptive data analyses are listed in Table 1.



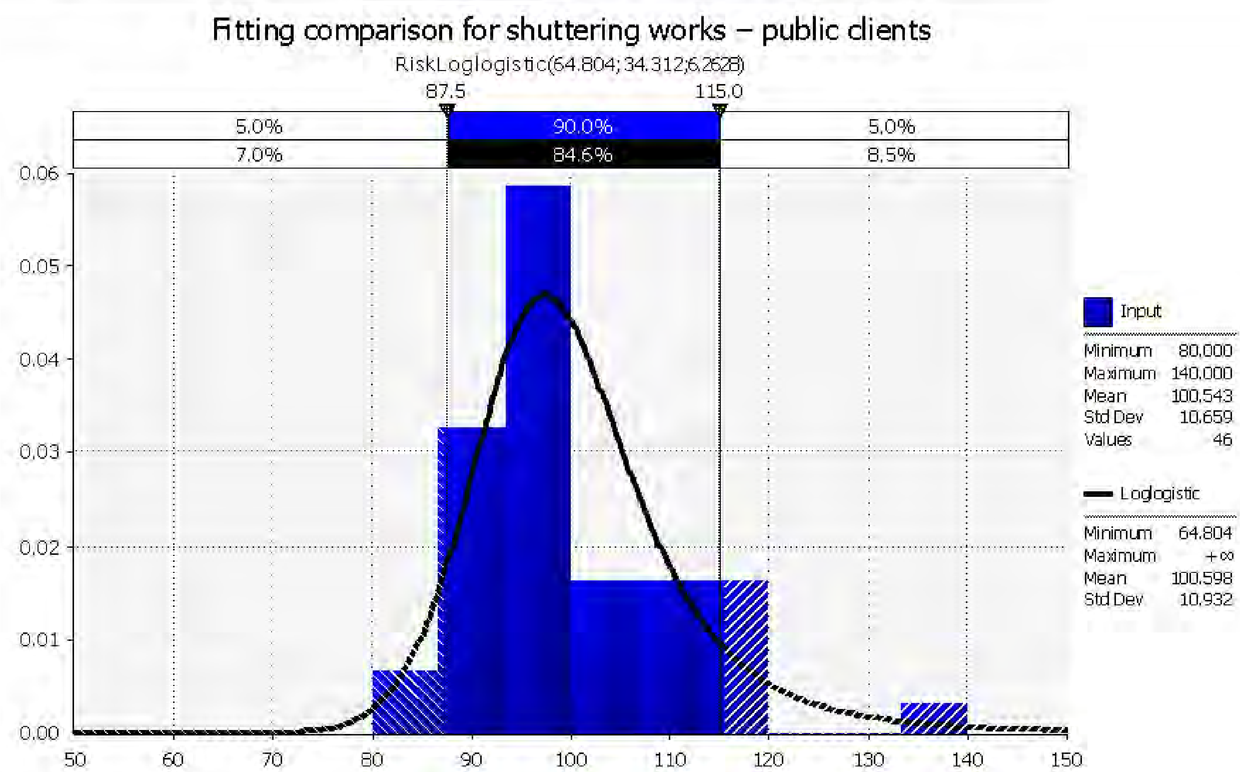


Figure 2: Data fitting – quantity deviations in shuttering works – top: private clients – bottom: public clients

The @Risk software suite was used to perform data fitting on the basis of expert responses for public and private clients (see Fig. 2) to enable realistic recommendations for potential distribution functions that would appropriately represent quantities in shuttering works. In both cases (i.e., public and private clients), LogLogistic distributions reflect the expert statements very accurately, as confirmed by a KS test (Kolmogorov-Smirnov test).

A direct comparison of the ranges of quantity deviations derived from expert responses shows that they expected a wider range for public clients, especially for quantity increases in shuttering works. Fig. 1 illustrates the spreads of related expert statements.

For shuttering works, experts generally considered quantity increases to be more likely than quantity reductions. However, the range of all responses received for public clients reveals a much greater spread of quantity deviations (60%) than for private clients (40%). The calculated range of M-estimators is roughly identical for public and private clients.

5. Conclusions

Overall, the results of the expert survey show that quantity uncertainties in shuttering works are considered to be greater for public clients than those assumed for private clients. For both data bases (i.e., public and private clients), fitting enabled the identification of LogLogistic distributions as the best approximation. However, the open end of this theoretical type of distribution should be viewed critically. This would mean that there is no defined upper limit to the formwork quantity. If probabilistic calculations are performed using such distributions (with no upper limit), this may lead to exceedingly implausible individual results within the simulation.

It is thus useful to combine the findings of the survey and the results of mathematical/statistical data fitting with theoretical considerations, particularly with respect to possible limits to individual parameters. In this case, the process of selecting the most appropriate distribution function could give rise to a LogLogistic-similar distribution that has the basic shape of a LogLogistic distribution whilst its upper end is closed by a defined limit (Hofstadler and Kummer 2017).

Furthermore, it should be noted that the selection of the most appropriate distribution function is not the only factor that influences the derived outputs of a probabilistic calculation. Due consideration should also be given to correlations between individual input parameters (Kummer and Hofstadler, 2017).

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Going for Waste to Energy in Developing Countries

Dr. Shahid Mahmood
(Director, Capital Development Authority, Islamabad, Pakistan)
cda_shahid@yahoo.com

Mohammad Arshad Chuhan
(Director Planning, Capital Development Authority, Islamabad, Pakistan)
mac_chouhan@hotmail.com

Abstract
Municipal solid waste (MSW) is a global environmental problem. Its quantity is increasing with corresponding increase in population. Safe disposal of MSW is a big challenge for municipal authorities. One way of disposal of MSW is in landfill sits and the other is to make its beneficial use as fuel for power generation.
MSW is easily available in abundance and is a cheap source of energy for power generation. Solid waste incinerator can remove up to 99.9999 percent of all toxins from their emissions and as such are no more harmful to the environment; in comparison MSW landfills emit methane-gas, and leachates that are hazardous for environment and ground water.
This research study has examined the possibility of waste to energy project for capital city of Pakistan, and has carried out its technical and financial feasibility analysis. This technically feasible and cost effective project will not only solve the MSW disposal problem, but would improve the environment of the city along with providing electricity and saving precious foreign exchange used for import of fuel.

Keywords
Municipal Solid Waste, Waste to energy, Power generation, garbage incineration, Refuse Derived Fuel

1. Introduction

Municipal solid waste (MSW) is mostly generated by human, it is the surplus and worthless stuff not needed at their homes, offices, factories and hospitals etc. MSW quantity is increasing with corresponding increase in population. Safe disposal of MSW is a big challenge for municipal authorities. MSW is mostly being dumped away from cities without any treatment. There are many ways of making beneficial use of MSW along with its disposal with less or no damage to environment. It is now possible with available technologies to remove toxins up to 99.9999 percent during energy recovery process (Khanjan et al. 2014).

MSW is easily available in abundance and is a cheap source of renewable energy for developing countries. Using MSW as energy source would not only solve the garbage disposal problem but would also have a positive impact on the environment. It has been examined in this study if waste to energy project can be executed in capital city of Pakistan, and technical and financial analysis have been carried out to support the decision making process. Waste to energy project will (not only solve the MSW disposal problem, but would also save the precious land used for landfill along with improving the environment of the city and saving precious foreign exchange used for import of fuel.

1. Study objective and scope

The purpose of this study is to find out, if this project is technically and financially workable and would it be worth to invest on this project ? What measures are required to be taken to make it possible to execute the project?

2. The Project Environment

2.1 **Organizations involved**: (i) Municipal Corporation Islamabad (ii) Private sector/technology and service provider (iii) Islamabad Electric Supply Company (IESCO)

2.2 **Input/output**

Input would be MSW/garbage and output would be electricity and recyclable material

2.3 **System interaction**

It would be dependent on the garbage collection system of Municipal Corporation Islamabad (MCI) and its delivery to the power plant.

2.4 **Physical environment**

Sufficient spaces and locations are available around Islamabad, where the plant can be established. There will no emission of foul gases during incineration; therefore, the environmental problems will not arise.

2.5 **Functional objectives**

In case, the project is technically and physically feasible. Arrange a financer and take up the matter with MCI for an agreement to provide garbage free of cost and obtaining/lease a piece of land for setting up the power plant. Environmental friendly disposal of MSW is also a big objective.

2.6 **Performance objectives**

Utilizing 750 M. ton MSW per day and generating 18750 kwh electricity, i-e 25 kwh of electricity is produced from each ton of garbage processed at Energy Plant in Baltimore Maryland. According to a Chinese report they are producing 225 Kwh per ton of RDF (refuse derived fuel) (Luhe and Cugu-2010). According to Florida State University the electricity production is 500 Kwh per ton of MSW (Demers-2009). We have used the most conservative estimate of 25 Kwh.

3. **Assumptions and constraints**

i. MCI would agree to provide all the generated MSW free of cost. (ii) Financer would be available (iii) No problem in transfer of technology (iv) IESCO will purchase the power produced, at a reasonable price

4. **Methodology**

The information available in the literature and primary data from the local organizations and MCI has been explored. Ground realities have also been analyzed to find out a technically and financially feasible project.

5. **Evaluation criteria**

Cost comparison has been carried out to know if energy produced by MSW is compatible with its close competitor i-e Coal. The cost of electricity produced has also been estimate along with Return on Investment (ROI), and payback period to arrive at a calculated decision.

6**. Literature Review**

6.1 **Availability of raw material for Waste to Energy project**

According to a brief/report of ministry of environment Pakistan (2008), the rate of waste generation on average in major cities of Pakistan from all type of municipal controlled areas varies from 0.283 kg/capita/day to 0.613 kg/capita/day or from 1.896 kg/house/day to 4.29 kg/house/day in all the selected cities. Islamabad city is generating about 0.5 kg per capita/day i-e 1000 M. tons of garbage (MSW) per day out of which about 750 m ton is collected. The major source of waste generation in Islamabad is from households and institutions, commercial establishments including organized markets, wholesale establishments, weekly markets, retail markets, health care facilities and slaughterhouses. The garbage mostly comprise of paper, plastic, polythene bags, glass, metal, ceramics, vegetable/fruit peals, bones and cloths etc. more than 90% garbage is organic material and combustible.

Table-1 Composition of MSW (Ministry of Environment-2008)

MSW Composition Item	1999 Study Percent	Decomposable Percent	EPA 1999 Generation
Paper	34.2%	34.2%	38.1%
Plastic	11.0%	0%	10.5%
Metals	4.4%	0%	7.8%
Glass	2.7%	0%	5.5%
Organic Materials	27.3%	17.2%	28.3%
Other Waste	18.3%	2.4%[2]	6.6%
Problem Materials	1.8%	0%	3.2%
HHW/HW	0.3%	0%	0%
	100%	53.8%	100%

Local available MSW contains moisture between 25 to 50% depending on the season and ambient temperatures. Technology is now available to tackle this problem and use it for power generation.

Table-2 Typical Composition of Solid Waste in Pakistani Cities (Ministry of Environment-2008)

Composition	%
Food Waste	8.4% to 21 %
Leaves, grass, straw, Fodder	10.2 % to 15.6 %
Fines	29.7 % to 47.5 %
Recyclables	13.6 % to 23.55 %

Almost 1/4th of the MSW comprise of recyclable material, it is due to this reason we see lots of scavengers roaming around garbage dumps in search of valuable materials.

6.2. Waste to energy technologies

Several types of incineration technologies are available today, and the most widely used are:

6.2.1 **Mass burning incineration**—with a movable grate

The mass burning technology with a movable grate has been successfully applied for decades and was developed to comply with the latest technical and environmental standards. Mass burning incineration can generally handle municipal waste without pre-treatment on an as-received basis (Thomas 2014). According to the World Bank report (1999) mass burning technologies are generally applied for large-scale incineration of mixed or source-separated municipal and industrial waste.

This technology is being successfully and extensively used in USA, Germany, Netherlands, France, Japan, Sweden and many European countries for last 25 years. According to Pak, (2006) Japanese are disposing off their 75% garbage through incineration, power generation facilities are implemented in only 20.5% among 1347 garbage incineration plant in Japan (in 2004). Garbage incineration reduces the volume of MSW by more than 90% due to which a very little space is required for disposal of ash in landfill.

6.2.2 **Rotary kilns**
Compared to movable grates the rotary kiln incineration plants have a smaller capacity and are mostly used for special types of waste unsuitable for burning on a grate, such as various types of hazardous, liquid, and infectious waste

6.2.3 **Fluidized bed incineration**,

It is still at the experimental stage and should therefore not yet be applied

6.2.4 **As a preheating support process**
In this method low temperature steam produced at the garbage incineration plant is super-heated by using high temperature gas turbine exhaust gas, and is used to drive a steam turbine generator for generating electric power with relatively high total efficiency (Pak-2006). Multiple fuels are used in this system.

6.2.5 **Ultrahigh temperature gasification**.
This distillation process involves the application of intense, indirect thermal energy in the absence of oxygen which reduces the material to a combustible gas and a non-hazardous, non-leachable inorganic material. This fully integrated system which combines both waste disposal and recycling, creates no harmful residues or atmospheric emissions, provides an environmentally friendly solution of MSW treatment. The combustible gas is used to generate electrical power (Pyromex-2014).

6.2.6 **Gasification and pyrolysis**
These are some of the most effective waste to energy technologies available currently. These two technologies can be performed together to maximize the cost effectiveness. Pyrolysis needs an outside heat source, and this is supplied by the gasification process, making both processes together self sustaining. This reduces the cost of the process, making them both more cost effective. Waste to energy in this manner can create several forms of energy (Thomas 2014).

6.2.7 **Anaerobic digestion**
The waste is put in specially constructed digesters, and no oxygen is allowed in. It breaks down the waste at much faster rate, releasing greenhouse gases including large amounts of methane. This process can also create heat from the large amounts of microbial activity as the biomass is decomposing. It is a slow process used for small quantities of MSW (Thomas 2014).

6.2.8 **Fermentation**
This waste to energy technology can take biomass and create ethanol, using waste cellulosic or organic material. In the fermentation process, the sugar in the waste is changed to carbon dioxide and alcohol. Normally fermentation occurs with no air is present. Esterification can also be done using waste to energy technologies, and the result of this process is biodiesel. The cost effectiveness of esterification will depend on the feedstock being used, and all the other relevant factors such as transportation distance, amount of oil present in the feed stocks, and others (Thomas 2014).

7. **Technical Analysis**

Moisture content of city MSW is more than 25%, therefore it will require bringing down the Moisture content below 15% for making it easily burnable, otherwise energy recovery will be comparatively on lesser side. It will require installation of a kiln and use heat generated with burning of gas, RDF or using hot flue gases of plant. Moisture can also be reduced by dumping MSW in open sun light for few hours in hot weather before brining it to plant.

In order to resolve the Low Heat Value (LHV) problem, Dezhen (2007) suggested to use aged MSW from landfill sites along with fresh MSW. The aged MSW from the garbage dumps will need mechanical excavation before re-treatment and re-utilization; then the aged MSW undergo separation steps to separate combustibles from soil, stones, glass, bricks, etc. When using combustibles to produce RDF, they must be shredded to let blending combustibles and additives easier. Dezhen (2007) also suggested to use additives to help control acidic gas emission.

Around 70% of plastics in fresh MSW is polyethylene and polypropylene and 40% of them can be easily separated for re-utilization before putting the MSW in the furnace. If plastics were separated, the LHV would be even lower. In practice auxiliary fuel such as oil, or coal would be needed for stable and complete combustion (Dezhen-2007).

Since there is about 23% recyclable material in the MSW, therefore, sorting of recycle material before incineration will be beneficial for recovery of project cost. Recyclable material can be retrieved by installing a separator in between kiln and the furnace hopper.

8. **Financial feasibility**

Table-3 Comparison of calorific value of RDF with its competitors (Shahid & Sohail-2013)

S #	Fuel	Calorific value kcal/kg	RDF equivalent (1kg fuel = kg RDF)
1	Coal (lignite)	4400	1.47
2	Furnace oil	10,000	3.33
3	Natural gas	13000	4.33
4	RDF	3000	1.00

If we compare the energy produced by MSW with its closest competitor "Coal" it reveals that 1.00 M Tons of Coal is equivalent to 1.47 M Tons of RDF. In Islamabad. The coal costs about Rs. 6200.00 or (US$ 55.85) per Metric Tons, whereas RDF costs according to Table-5 works out to about Rs. 859.52 per M. Ton. It means that RDF amounting Rs. 1263.50 can generate heat equal to coal costing Rs. 6200.00 with a saving of Rs. 4936.50 or 79.62 %.

Table-4, Material and Energy Consumption during Making RDF from Aged MSW (Dezhen-2007**)**

Step	Aged MSW mining Separation	shredding and blending	RDF production
Energy & material consumption	Oil: 0.7kg/ton aged MSW	Electricity: 0.75kwh/ton aged MSW	Electricity: 0.7kwh/ton RDF CaO: 80kg/ton RDF

Table-5, Cost of making RDF from aged MSW (Shahid and Sohail -2013)

In put	Qty	Unit	Rate	Amount Rs.
Oil	0.7	Kg	55	38.5
Electricity	1.45	Kwh	14.5	21.02
CaO	80	Kg	10	800.00
Total cost of making RDF from MSW per ton			Rs. US $	859.52 7.74

Table-6, Cost estimate of the project:

	1. buildings, plant & machinery	Amount in m US$	
A	Civil works	LC	FC
	Incineration & power generation	0.200	
	land filling	0.200	
	composting	0.050	
	Sub total	0.450	
B	Foreign machinery		12.500
	Land filling equipment		1.500
	Incineration & power generation equipment composting		1.350
	sub total		15.350
C	Insurance, clearance, inland freight etc @ 0.75%	0.119	
D	Erection @ 0.75%	0.119	
E	Financial charges during construction	1.000	
F	Contingencies @ 1%	0.158	
	Total (a to f)	1.845	
	Grand total		17.195
	2. Furniture and fixtures		
A	Furniture & fixtures	0.025	
B	Vehicles	0.075	
	Total cost of fixed assets (1+2)	17.295	
	O&m cost of plant @ 2% per annum	0.346	

8.1 **Annual revenue**

i. Production of electricity for sale assuming a plant factor of 0.7, the energy produced per annum =18750x330x24x0.7=103.95m kwh

Revenue/year with tariff rate @10 cent / unit = 10.395 million US$

ii. Recycled ferrous metal

Daily generation = 3 ton @ US$ 225/ton.

Revenue=3x330x225=0.223 m US$

iii. Recycled plastic material

Daily generation = 20 ton

Revenue @ US$ 105/ton

= 20x330x105 = 0.693 m US$

iv. <u>Total annual revenue = 11.311 m US$</u>

8.2. **Annual Return on Investment**

Capital	= 17.295 m US$
Revenue	= 11.311 m US$
Expenditure	= 0.346 m US$
Depreciation	= 1.023 m US$
Financial gains=	9.942 m US $
ROI	= 57.48%

8.3. **Pay Back period** < 2 years

9. **Steps required to materialize the project execution**

- Induction of Consultants for preparation of design, documentation and supervision of the project
- Preparation of Environmental Impact Assessment (EIA) report and getting it processed for approval from Pakistan Environment Protection Agency
- Commitment and decision by MCI that MSW will be collected and supplied to the project using existing transportation arrangements free of cost
- Selection and approval of the technology and equipment for the project on the basis of report of consultants
- Approval from Gas supply company to provide required fuel gas for the project
- Human resource with appropriate training
- Capital of 17.295 US$ for a plant capacity to handle 750 M tons of MSW for producing 18750 kwh electricity.
- Agreement with intended consumer (IESCO) to purchase the electricity and make payments on monthly basis

10. **Findings**

- Furnace oil cost / ton has increased from Rs. 2,900 in 1994 to Rs. 45,000 (US$ 405) with an increase of more than 10 times during the last twenty-four years, therefore it is extremely essential to use alternative fuel source, which is easily available in the form of MSW.
- The MSW of Islamabad contains moisture between 25 to 50%, which would not be helpful for proper incineration. It can be used with little work on it.
- The raw material is easily available in abundance and certainly would further increase in future
- The project is technically & financially feasible
- Non-combustible recyclable material can be retrieved from the residue of the plant, which has a market value.
- Plastic material however will get burned because there is no sorting system in the mass burning incineration system used by industrialized countries.
- The MSW volume gets reduced by more than 90% therefore comparatively very small land fill site would be required. The ash is also useable in road construction projects for stabilizing earth.
- The project would have a positive effect on the cities environment
- MCI's assistance would be required to supply the MSW free of cost and CDA will provide a piece of land on lease for setting up the power plant

- Power generation prices from MSW are competitive as compared to its close competitor coal
- There are many potential customers of electricity, like IESCO, CDA, local industry and private housing schemes etc
- Overall impact of project is positive

11. Recommendations

- Put up a plant with a capacity of 750 M tons per day
- Preferably two production lines be established, each having capacity around 375 M. Ton per day.
- Devise a mechanism to reduce the moisture of MSW to at least 15%, by preheating using the flue gases or by drying it in open sunlight.
- There is plenty of recyclable material in MSW (between 13 to 24%); it should be sorted out (especially metals, glass, plastics, rubbers, and un-combustible materials) before putting it in receiving hopper.
- The project cost can be invested by MCI, or the investor may be asked to build, operate own and transfer (BOOT) with some concessionary period.
- The terms of reference must include the condition with the understanding of MCI and CDA that MCI shall ensure supply of MSW to power plant as per requirements free of cost and CDA shall lease out an approachable piece of land for setting up the power plant.
- Garbage disposal charges may also be levied on the garbage generators at some appropriate and proportionate ratio that may be collected by MCI to recover the project cost.

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Reactive Powder Concrete Application in the Construction Industry in the United States

Amin K. Akhnoukh
Associate Professor, East Carolina University, Greenville, North Carolina, USA
akhnoukha17@ecu.edu

Roberto Soares
Teaching Assistant Professor, East Carolina University, Greenville, North Carolina, USA
soaresr17@ecu.edu

Abstract

Reactive powder concrete (RPC) is a new class of concrete developed in France in the 1990s. RPC mixes shows superior material properties as high early strength, higher compressive and tensile strength, durability and higher resistance to shrinkage, creep, and hard environmental conditions. Currently, RPC is introduced to the US market through the FHWA and is commercially known as *ultra-high-performance concrete* (UHPC).

UHPC displayed superior performance in high-rise building construction and prestressed concrete girder bridges. The high early strength results in expedited fabrication at precast yards. The RPC high strength results in smaller cross sections, lighter weight structures, reduced labor, and construction equipment with smaller capacities. In 2010, the FHWA started using RPC in various bridge construction and repair projects using the accelerated bridge construction (ABC) innovative approach. This paper presents the history of RPC, RPC mix constituents, advantages, and its application in prefabricated bridge elements and systems construction (PBES).

Keywords
Reactive Powder Concrete (RPC), Ultra-High Performance Concrete (UHPC), Pi-girder, Compressive Strength

1. Introduction

Reactive powder concrete (RPC) is a new class of concrete that has been developed in France in the 1990's. When compared with other types of concrete, RPC shows superior material properties as high early strength, higher tensile and compressive strength, durability, and higher resistance to shrinkage, creep, and hard environmental conditions. In early 2000s, the Federal Highway Administration (FHWA) and State

Departments of Transportation (DoTs) introduced the RPC mixes to the US construction industry with emphasis on long-span prefabricated bridge girders. RPC is commercially available in the US market under the name ultra-high-performance concrete (UHPC).

Standards and specifications for RPC are set by different scientific societies in Europe and Japan. The Japan Society of Civil Engineers (JSCE) *Recommendation for Design and Construction of Ultra-High Strength Fiber Reinforced Concrete (draft)* (JSCE, 2006) defines the UHPC as a type of cementitious composite reinforced by fibers with characteristic values in excess of 150 N/mm2 (21.7 ksi) in compressive strength, 5 N/mm2 (0.73 ksi) in tensile strength, and 4 N/mm2 (0.58 ksi) in first cracking strength. The UHPC matrix should be composed of aggregates; whose maximum particle size is less than 2.5 mm, cement and pozzolans, and water-to-powder ratio is less than 0.24. UHPC contains random reinforcing steel fibers of more than 2% (by volume), whose tensile strength exceeds 2 x 103 N/mm2 (290 ksi), and ranges from 10 to 20 mm in length and 0.1 to 0.25 mm in diameter. The Association Francaise de Genie Civil (AFGC) *Interim Recommendations for Ultra-High-Performance Fiber-Reinforced Concrete (2002)* defines the UHPC as a material with a cement matrix and a characteristic compressive strength in excess of 150 MPa (21.7 ksi), and containing streel fibers in order to achieve ductile behavior. According to the AFGC, the following are the main difference between the UHPC and other types of concrete:

- Higher compressive strength
- Incorporation of random steel fibers in the mix, which ensures the non-brittle mix behavior, and alters the conventional reinforcement of passive reinforcement
- High binder content and special selection of aggregates

Different UHPC proprietary mixes are available in the international markets with standard characteristics. Example of the proprietary mixes are BSI "Beton Special Industrial" (Special Industrial Concrete) developed by Eiffage, Cemtec by LCPC, and different kinds of Ductal concrete resulting from a joint research by Bouygues, LaFarge, and Rhodia. Ductal concrete marketed by LaFarge and Bouygues is the only proprietary RPC (UHPC) mix available in the US market. This paper presents main mix constituents for the proprietary RPC mix available in the US market, its advantages, and the main impediments that delays the widespread of RPC in construction projects in the local and international markets.

2. Reactive Powder Concrete Main Constituents

The RPC mix constituents are proportioned to achieve an optimized packing order by reducing the voids ratio of the granular constituents of the RPC. The granular mix constituents include fine sand, cement, quartz flour, and micro-silica (silica fume). The largest granular material available is fine sand, with a particle size ranging from 150 to 600 µm. Cement particles have the second largest size in the mix, with a nominal size of 10 µm. Micro-silica is the smallest particle with the RPC mix, with a diameter of 1 µm. The micro-sized silica particles have a small diameter sufficient to fill the voids among the mix constituents, hence, it increases the packing order and positively impact the strength and long-term performance of the RPC.

Random steel fibers are added to the proprietary RPC mix to ensure its ductile behavior and increase the tensile strength of the mix. Fibers are the largest mix constituent, with a nominal diameter of 0.008 in. and a length of 0.5 in. Its average modulus of elasticity (E) is 29,800 ksi, and the average ultimate strength is 474 ksi. Steel fibers are separately added to the mix ingredients, and represent 2% of the final volume of the mix, and 6% of its weight. Steel fibers are a major contributor to the concrete high compressive strength, in addition to its major role in the RPC mix ductility, and enhanced long-term performance as low shrinkage and low creep. The design of the standard RPC mix marketed in the local construction market within the United States by LaFarge-under the commercial name Ductal is shown in the Table (1)

Table 1: UHPC Mix Composition (Publication No. FHWA-HRT-06-103)

Material	Amount (lb/yd^3)	Percent by Weight
Portland Cement	1200	28.5
Fine Sand	1720	40.8
Micro-Silica	390	9.3
Quartz Flour	355	8.4
Super-plasticizer	51.8	1.2
Accelerator	50.5	1.2
Steel Fibers	263	6.2

3. Reactive Powder Concrete Mix Properties

The mix composition of the RPC includes a high binder content (approximately 1950 lbs per cubic yard) as compared to 500 lbs per cubic yard in a regular mix results in a higher compressive strength. The presence of steel fibers contributes to the increased compressive strength and results in a higher ductility for the RPC. In a recent study, proprietary RPC mixes had a 28-day compressive strength of 25 ksi, and non-proprietary mixes excluding the steel fibers had a compressive strength of 18 ksi at the same age (Akhnoukh and Xie, 2010). RPC mixes are characterized by a higher density due to its higher packing order, and reduced voids ratio. Standard proprietary mix designs have an average density of 150 to 155 pcf, as compared to densities of 142-145 pcf for conventional concrete mixes.

Recent research studies have investigated the optimum mixing regimen to produce RPC mixes with superior mechanical properties and long-term performance characteristics. Based on research findings, the following steps are considered when mixing RPC:

1. Preblended granular material are added to the batch plant mixer for dry mixing for a total duration of 2-3 minutes
2. One-half of the super-plasticizer amount is added to the total weight of mixing water. Mixing water should be of a very low temperature (close to freezing point). Super-plasticizer and cold water are blended together outside the concrete-mixer
3. Mixing water and superplasticizer are slowly added to the concrete mixer containing the dry mixed granular material. Wet mixing continues for 15-20 minutes
4. The remaining amount of super-plasticizer is added to the mixer. Mixing continues for 5 minutes
5. Random steel fibers are added to the mixer. Fibers are slowly added to ensure the even distribution of steel fibers within the produced RPC mix.

The afore-mentioned mixing procedure spans for a total period of 30 minutes, which is adequate to produce a mix with optimum rheology without impeding the work progress in batch plants. RPC produced using this mixing regimen attain the following characteristics:

- **Compressive Strength:** exceeds 2.7 ksi as per standard specifications. Research studies reported an average 24-hour compressive strength of 12-14 ksi, and a 28-day compressive strength of 24
- **Post-Cracking Strength:** of 1.6-1.8 ksi due to the ductile behavior achieved using random steel fibers within the mix.
- **Modulus of Elasticity:** at release is 5000 psi and is approximately 7500 psi at 28 days. This high value of modulus of elasticity is beneficial in reducing deflection and meeting serviceability requirements of high-way bridge girders.
- **Corrosion Resistance:** are increased in RPC concrete due to the higher packing order of the granular materials, which reduces the voids ratio and minimizes the chloride attack to the reinforcing steel and prestress strands embedded in the RPC structural members
- **Freeze and Thaw Resistance:** RPC mixes are characterized by superior freeze and thaw cycles resistance due to the high packing order of its granular materials, and the lack of air voids within the concrete. The lack of voids results in the absence of free space for water to freeze and increase in volume.

The superior characteristics of the RPC beams fabricated using proprietary mixes as Ductal allows for the design of bridge girders with very high span-to-depth ratios. Span-to-depth ratio of 30:1 was achieved in multiple bridge projects, resulting in lighter weight and more durable bridges. A comparison of depths of different I-girders with similar capacities produced by regular RC mixes, RPC mixes, and steel are shown in Figure 1.

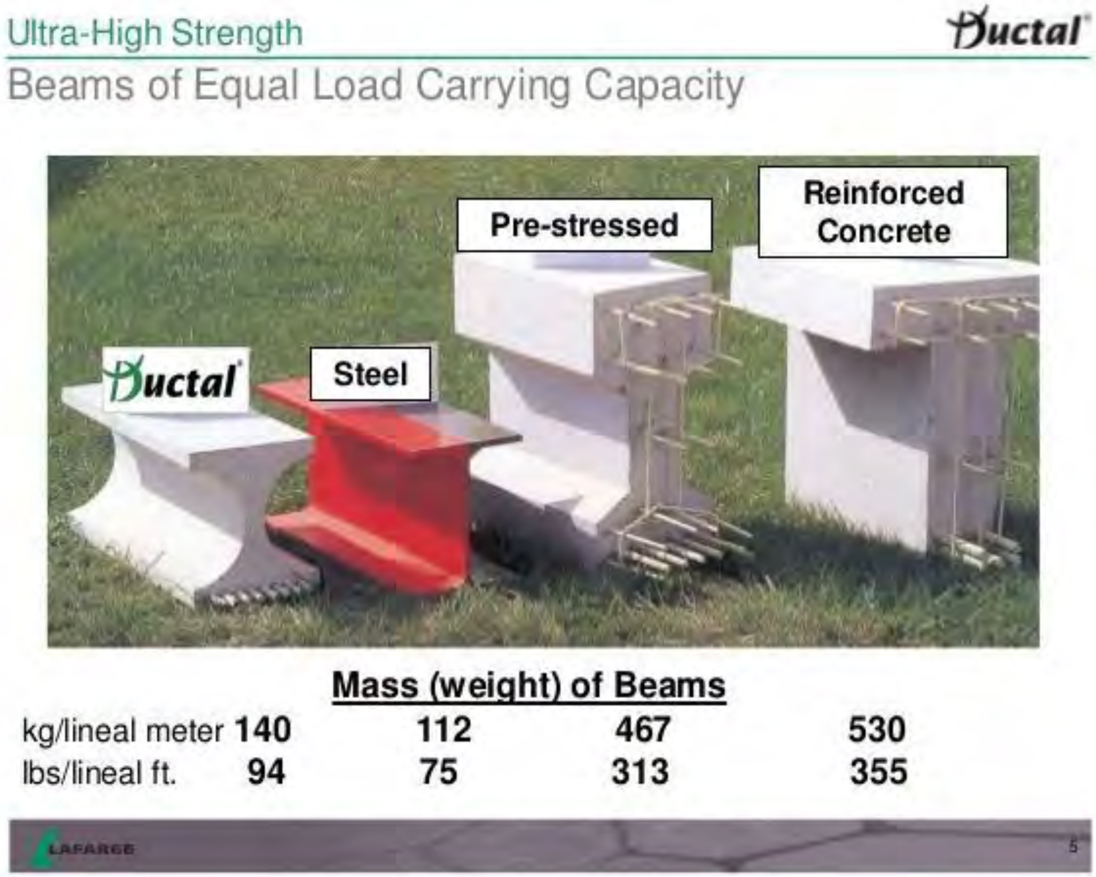

Figure 1: Comparison of Bridge I-Girders with Similar Capacities and Different Materials (ASCE, 2016)

4. Major RPC Construction Projects

The FHWA is currently funding State DoTs to investigate the potential of using proprietary RPC in their new projects. Iowa Department of Transportation utilized available federal funding to construct the first highway bridge in the United States using RPC, known as the Mars Hill bridge. The Mars Hill bridge was constructed in Wapello County, Iowa as a single span bridge using 110 ft. span Iowa Bulb Tee girders. The ductility and high strength of the RPC mixes enabled the designers to use large-number of 0.6-inch pretressing strands and use fewer girders in bridge construction, which expedited the bridge construction process (Aaleti, 2011). The Mars Hill RPC bridge is shown in figure 2.

Figure 2: Mars Hill RPC Bridge Constructed in Wapello County, Iowa (Aaleti, 2011)

The success of Mars Hill RPC bridge construction encouraged researchers at the MIT to design an innovative Pi-shaped bridge girder that includes both bridge girder and bridge deck. The full-scale testing of the Pi-girder indicated a reduced torsional capacity due to the slenderness of the girder. The conclusions of this testing program suggested further optimization of the girder dimensions.

The optimization of the Pi-girder at the FHWA labs resulted in a 2nd generation Pi-girders with improved structural strength. The modifications introduced to the original Pi-girder failing the full-scale test included an increased deck thickness and width, increased web (girder) thickness, and decreased web spacing. The refined design of the 2nd generation Pi-girder targets an increased torsional capacity and improved girder serviceability.

The 2nd Generation Pi-girder is design as a modular component. The width of the girder is 100 inches (perpindicular to traffic direction), the depth of the girder is 33 inches, and the thickness of the slab is 4.1 inches. The girder bulb can accommodate up to 16 prestress strands. The afore-mentioned design enables the girder to span for a distance of 87 ft. without violating any of the AASHTO LRFD Bridge Design Specifications. The span-to-depth ratio of the 2nd generation Pi-girder is 31:1, which allows for material savings, lighter structure, and minimize the need to heavy construction equipment. The 2nd generation Pi-girder is shown in Figure 3.

Figure 3: MIT Pi-Girder Fabricated Using RPC Proprietary Mixes (FHWA-HRT-09-069)

5. Summary and Conclusions

Reactive Powder Concrete (RPC) is introduced to the US construction market as a new type of concrete with superior mechanical properties. RPC mixes are characterized by compressive strength that exceed 21.7 ksi, which enables the design and fabrication with girders with high span-to-depth ratios. Due to the granular high packing order, voids ratios are minimized and RPC mixes have superior long-term performance due to its capability to resist freeze and thaw cycles, in addition to its high chloride resistance.

In recent projects, the FHWA incorporated RPC mixes in bridge construction. The first highway bridge fabricated using RPC mixes was built in Wapello County, Iowa. The high ductility of RPC mixes enabled researchers at the MIT to develop a new Pi-girder that was used in the accelerated construction of Buchanan County bridge in Iowa. Current research is focused on developing newer generations of economic RPC mixes to increase its market share in the US construction market.

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Claim Management - Fundamentals and Utilization for Industrial Construction

Abstract:
The subject of claim management is becoming more and more present in the construction industry. Taking a look at the industrial building sector, it becomes clear, that there are different boundary conditions compared to classic residential construction projects. These include very short construction periods in which significant areas have to be built. Meaning that most industrial buildings are single-storey buildings with a large floor space, that are built with precast elements as common construction method to be able to comply with short construction times.
To come up with possible further reasons for claims, in this research an interview guide was compiled and expert interviews were conducted with persons working in this specific sector. These opinion polls were deliberately conducted with non-standardized questionnaires to leave room for interviewers to provide answers and different interpretations of possible reasons for claims.
The results show, that claims in industrial construction projects mostly result from the client's sphere. Those can be cost increases due to changes in the project scope, but also decreases resulting from optional services that are not executed. Also the large base areas, which are typical for industrial structures, can increase the project budget. Poor groundwater discoveries repeatedly lead to performance problems and consequently to additional costs. In the process, the foundation risks are repeatedly passed on, which is also permissible within a reasonable scope (Kurbos, 2010).

Keywords:
Claim Management, Construction Contract, Industrial Construction

1. Introduction

In the execution phase of construction projects, cost overruns frequently occur. Additional or reduced costs arise in the event of a deviation of the contractually agreed services in comparison to the actually performed services or due to disruptions of the construction process (Oberndorfer, 2003).
The reasons for these disruptions are often not clear and can be diverse. The legal regulations and standards divide the risks and obligations of the contracting parties into two spheres. The client's and the contractor's sphere.
Sometimes, due to the complex nature of construction contracts, it is not clear from what sphere those additional costs result from (Kropik, 2014). Therefore, the investigation of recurrent additional claims in the field of industrial construction is the central focus of this research, but also the types of the tendered contracts, that can differ from project to project (Elwert and Flassak, 2010).

Due to the increasing number of projects, the space requirements and the required storage areas, industrial construction is a division that is becoming more and more present in the field of claim management. It is characterized by buildings with large areas and huge amounts of building materials, which have to be installed and manipulated within a short period of construction time. Also special flatness tolerances in concrete floors or special floor coatings that promote the later production operations in the building, contribute to the high number of claims. Those requirements are defined by the activities that are carried out in the building and by the client himself.
In the case of a clearly defined bill of quantities, there should be no cost overruns, but it happens again and again that even when meticulous planning and work preparation was done, the scope of service changes (Weselik and Hussian, 2011). This may be due, among other things, to the changed requirements that arise as a result of client's change requests during the execution phase, or to certain performance disruptions, such as a delayed start date of the construction works. Especially with the large construction volumes and the associated costs in industrial construction, change requests or disruptions can quickly have a negative impact on the construction costs.

2. Method

To answer the question where recurring additional costs in industrial construction result from, an interview guide was designed and expert interviews were conducted. The interview guideline deals with general conditions and specific structural aspects of industrial construction as well as the contract design and reasons for claims of this construction sector. The experts were also asked about possible solution strategies and the future development of industrial constructions.
The data was collected and recorded using a sound recording device and literally transcribed. The partially standardized, open questions were deliberately chosen in such a way, that the interviewees had a certain amount of freedom for answering their questions.
To analyze the problem of supplementary claims in industrial construction, the interview partners were given the opportunity to freely articulate their experiences and effects. The transcribed expert surveys were coded with the program MAXQDA. The topics of the interview guideline were coded and the statements of the interview partners on this topic were assigned to the respective topic.
A total of 9 expert surveys in the field of industrial construction were conducted with persons from different construction companies. The work experience of the interviewees was an average of 19 years.

3. Results

The results of the expert survey were evaluated using the codes from the MAXQDA program. The structure is analogous to the interview guide. Initially, industrial construction is defined in terms of structural and general constraints and characteristics. Thereafter, the contract designs are considered and finally the reasons for additional cost claims are discussed.

3.1 Boundary conditions and characteristics of the industrial construction

Industrial construction comprises the totality of all construction facilities that are necessary for an economic production process of goods. This process includes all production steps and transport routes inside the building, from the delivery of the raw material to the storage and the shipment of the finished product (Maier-Leibnitz, 1932). In this sense, industrial buildings are buildings, which are used for the production (utilization, treatment and distribution) or storage of goods and products. In other words, industrial buildings are production halls, warehouses or logistics halls (see Figure 1).

Especially in logistics halls, high requirements on the flatness and the surface condition of the floors are imposed. The reason for those high requirements is often the system that is later used for the manipulation of products and goods. E.g. if autonomous, induction-guided stackers are used, the highest demands on the flatness of the soil are imposed, in order to ensure an economical conveying process.

Most of the processes inside the building run at all scales of economic efficiency, so it is necessary that the construction of the building proceeds in the same way and supports this efficiency. This does not mean that e.g. building a residential building does not have to be economical either, but in industrial construction it is a question of using the cheapest and most economical means to build an object that enables the end customer to use it for a long period and still fulfill his core tasks.

Furthermore, in most cases no elaborate architecture has to be considered as such, but it is important to optimize the used construction methods and to plan the construction process meticulously in advance. So to say, the form of the building follows its function.

Another characteristic of industrial construction projects are the very short construction times defined by the client. As soon as a project is approved, every client wants to put his object into operation as soon as possible, so that a possible intermediate financing period is kept as low as possible. Furthermore, the client's operations continue during the construction phase in other production buildings, which also cause costs for the client. To meet the strict deadlines, executing companies are forced to use prefabricated elements. Therefore, the prefabricated construction method established itself as the most common construction method in industrial construction.

Also mentioned in the abstract, one big difference to other building projects is, that industrial buildings mostly are one-storey. This is a big advantage in terms of the construction phase, because contractors are not depending on building one floor above the other. Theoretically, workers can start the construction works simultaneously at every corner of the building. The earthworks, for example, must not be completed at one end of an industrial building in order to be able to move precast columns at the other end.

A summary of the features and structural constraints is shown in Figure 1.

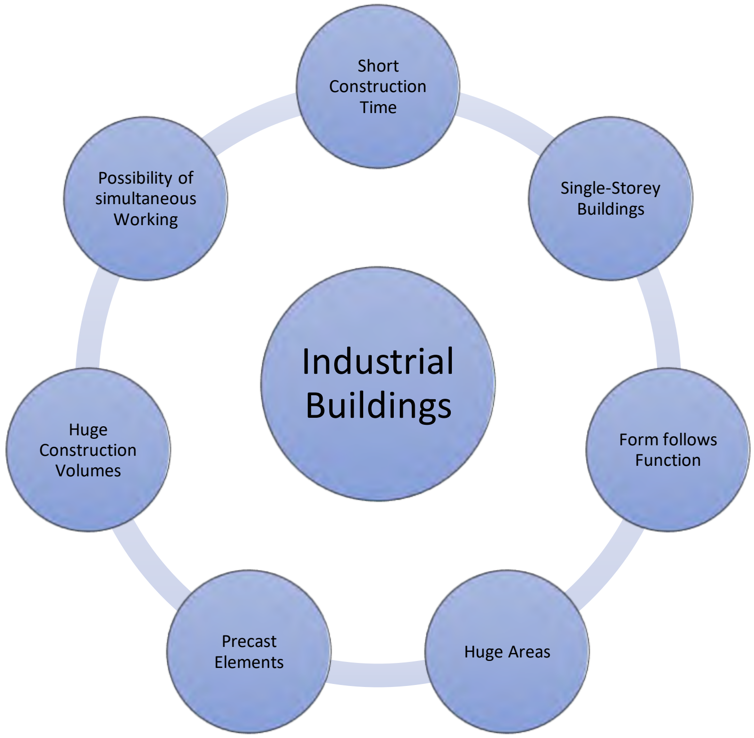

Figure 1: Boundary Conditions in Industrial Construction

3.2 Contract Design

According to the experts, a trend that can be observed in industrial construction as well as in general in the construction industry is the tendency towards general contractors, - partial general contractors and total contractor contracts with lump sum payments. The reason for choosing lump sum prices is, that in industrial construction a lot of construction processes take place at the same time. So if one considers the high project volumes and the short construction periods, simply spoken, construction managers just wouldn't have sufficient time to measure up the masses or quantities of every single construction process in order to bill them separately.
Modern clients want the greatest possible security in the contracting process when awarding an industrial construction project, as the investment sums are very high. Therefor, total contractor contracts are becoming more common. The big advantage of this type of contract is that the executing company can already be involved in the design phase of the construction project and thereof can help to figure out the most efficient and economic way to execute the construction works in order to not overrun the budget and develop realistic schedules.

Figure 2 illustrates the experiences that experts have made regarding contract designs. According to this, 66.67% of the interviewees stated, that a general contractor agreement is the most frequent form of construction contracts. The remaining 33.33% have the most experience with total contractor contracts. According to the interviewees, 77.78% of the general contractor contracts are lump sum and 22.22% are billed according to the actual executed services with a unit price contract. In the case of total contractor agreements, all experts agreed, that they are billed as a lump sum.

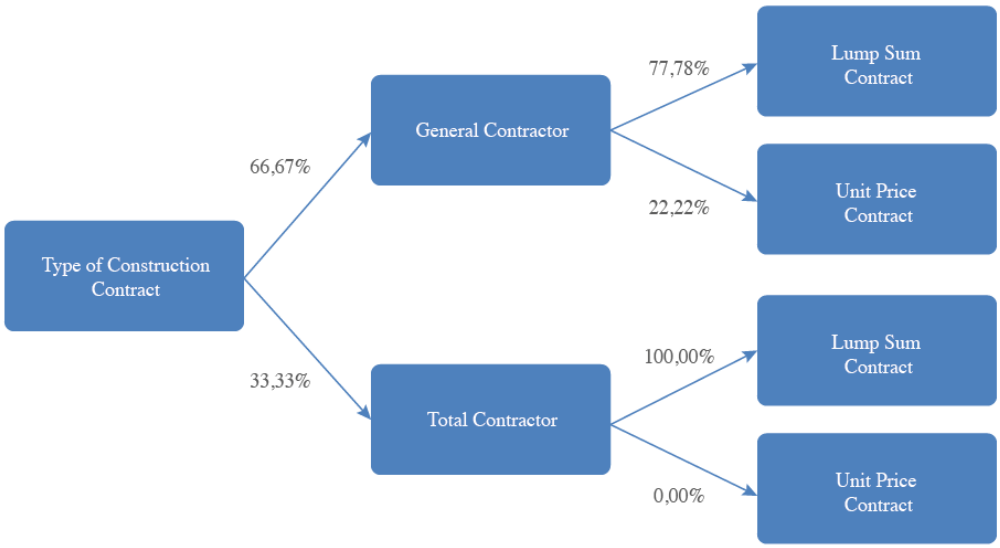

Figure 2: Contractual Designs in Industrial Construction

3.3 Claims in industrial construction

It was difficult for respondents to allocate additional cost claims to certain services or trades. Each construction project is different, so it is complicated to make a general statement about service items or trades where additional cost occur in each and every project. A possible allocation to additional costs must therefore take place where they directly arise, e.g. where either services are changed or the construction process is disturbed.
However, when one considers the boundary conditions in industrial construction, there are certain trades, where the interviewees agree that even in divergent projects claims arise analogously.
Particularly named was the trade of earthworks. Due to the size of industrial structures and high punctual loads that can occur, high demands are made on the building ground. Even though that is common knowledge, the ground is often explored in an inadequately selected grid. This means that the distances between the individual soil samples are too large and the ground between the sample fields can behave differently than stated in the soil survey, which can lead to major problems when the foundation works are executed.
The experts agreed, that the client should plan his financial resources adequately, so that there is a sufficient budget for the subsoil exploration. If this is not done properly and the structure of the soil behaves differently, the client has to expect additional costs, if the risk has not been passed on

to the contractor by contractual clauses. This passing on of risks has to be considered as reasonable. So if a proper soil survey and soil engineering investigations have been documented to a sufficient extent, the client will try to pass on the risk of the subsoil in the construction contract. But if the soil survey presents the soil differently than it is found on the construction site, the executing company will confront the client with claims.

When clustering the reasons for claims, the interview partners agree that the biggest influence lies with the client and his subcontractors (mostly planners). Many of the claims result from change requests made by the client. Therefore, it is very important that the requested services and project specifications are clearly defined in advance and with which systems he intends to work in and how exactly he wants to use his building. Furthermore, planners and subcontractors are also cited as reasons for the occurring claims because the quality of the provided documents (e.g. the planning depth or the bill of quantities) is often insufficient.

It also makes a big difference whether one wishes to conclude several projects with the client or has already worked as contractor for him in the past. The organizational structure of the claim managements of the contracting parties is an essential topic for the partnership-based completion of a construction project. Meaning, that an executing company will not begin claiming if it is not really mandatory. Unfortunately the 7 experts also stated, that there are many clients, but also contractors, which try to force the other party strategically with targeted cost management.

It can be said that in industrial construction certain industries, such as the trade of earthmoving, the possibility of receiving claims as a client are very high (see Figure 39). 100% of the experts agree, that the client always causes additional cost claims. The aspects of the subsoil and the planning can also be attributed to the client's sphere. Therefore, every client is advised to have his objects planned by a planner with suitable references in industrial construction. It is crucial how well he prepares for the construction project and how exactly he defines the required services.

With 55.56% of the entries earthworks and the subsoil risk were mentioned as reasons for recurring claims. In this regard, the subject of the subsoil risk and the subsoil survey has already been discussed. Figure 3 should clarify the reasons given in the interviews for additional cost claims according to the frequency of their entries.

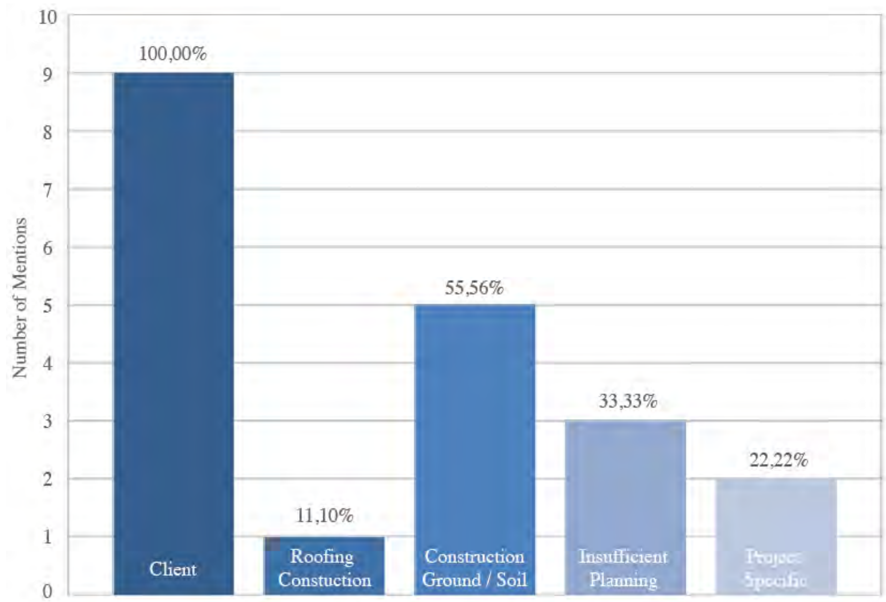

Figure 3: Reasons for Recurring Claims

3.3 Solutions for avoiding claims

The approaches for avoiding or reducing additional cost claims lead to analogous results in the conducted interviews. The best solution strategy, mentioned by the experts, would be to involve the executing companies as early as possible in the project, because it makes both parties have certain obligations when the construction itself starts.
One of the reasons for that is, that a company is, that the planning can address both the constraints of industrial construction and the strengths and weaknesses of the operational unit on the construction site. So together, the parties can plan an efficient and logistically optimized construction process with the best methods for the specific project.
So as a recommendation for the client, it can be generalized, that the most cost certainty can be achieved, when the project is thoroughly planned with clearly defined properties and functions. This guarantees a complete bill of quantities and avoids change requests made by the client during the construction phase. If, additionally, the executing company is already involved in the planning of the project and a general or total contractor contract is tendered, the cost certainty even increases.

4. Conclusion

Since it is expected that clients require contractors to realize buildings in shorter and shorter construction periods, it is essential, that all aspects of the work execution are already taken into account in the planning phase.

In the opinion of the author, special attention has to be paid to the determination of the most economical construction methods for the defined large properties of the building. Thanks to research in the field of concrete technology and the precast industry, those high demands can be realized efficiently and the short construction times can be met.
If the client is aware of the characteristics of his buildings, and these have been exhaustively described before the construction contract is concluded, the interviewees believe, that no change requests will occur.
The development of the subject of additional cost claims in industrial construction depends largely on the clients and their planning subcontractors, but also on the know-how of the executing companies. In the case of integrally planned construction projects, the number of claims can be reduced to a minimum.
However, the most important point in the construction of a building should never be forgotten. It is still the people that are building the projects and this fact must be taken into account in every construction period calculation, work preparation and execution of a project. Because wherever people work, mistakes can and will happen.

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Improving Productivity of Concreting Equipment: Failure Modeling

Case Study on New Hot Strip Mill, Rourkela, India

Arka Ghosh
M.Tech. Student, Department of Civil Engineering, Indian Institute of Technology, New Delhi, Delhi, India
Arka.Ghosh.cec16@civil.iitd.ac.in

Abid Hasan
Ph.D. Candidate, University of South Australia, Adelaide, Australia
abid.hasan@mymail.unisa.edu.au

Kumar Neeraj Jha
Associate Professor, Department of Civil Engineering, Indian Institute of Technology, New Delhi, Delhi, India
knjha@civil.iitd.ac.in

Abstract
There is a growing reliance on concrete batching plants and ready-mix concrete presently due to faster work, uniform quality of concrete, eco-friendly nature and reduction in wastage. Rapid changes in the type of equipment and technological advancement has restructured the dynamics of the construction industry. Hence improving the productivity of Concrete Batching Plants and their supporting equipment will ensure better quality, durable and robust infrastructure development economically and sustainably. The high variability in site concreting operations, complex problems in logistical and combinational optimization are major hindrance factors that affect effective management strategies/procedures. Overall Reliability of the System (Concrete Batching Plant and Transit Mixer) is calculated using k out of n method algorithm developed by Barlow Heidman. A regression model is then developed for each of the equipment that tries to find out the factors on which the time to failure of a concrete batching plant depends upon and establishes a mathematical relationship with an acceptable level of accuracy. The model will act as a tool for future forecasting so that effective maintenance strategies can be duly formulated, and maintenance crew allotted/kept on standby just before the next failure to minimize loss of productivity due to equipment breakdown.

Keywords
Failure Modelling, Ready Mix Concrete, Overall Equipment Efficiency, Reliability.

1. Introduction

Since its inception in 1905 in Germany, the Concrete Batching Plant has undergone many modifications, and technological improvements to now serve as the backbone for infrastructural development. In the Indian context, it all started with the commencement of RMC plant in Pune in 1993. Although cement and concrete consumption is forecast to increase approximately at 3% to 4% globally, higher growth of about 6% to 8% is estimated to take place during the next decade in India. The construction industry is the backbone towards the proper growth and development of any nation. According to the Global Construction 2030 report, the amount of construction output will grow by 85% to $15.5 trillion globally by 2030, with primarily three countries, US, India, and China, taking the lead and explaining 57% of the global growth. The Global Construction 2030 report forecasts the average global construction growth to be 3.9% per annum till 2030 leaving behind even the global GDP by over one point (Global Construction 2030 Report, GCP, Oxford Economics, Mazloumian *et al.,*2015). The primary force behind this prediction is the continued industrialization of emerging countries and the developed nations coping with economic instability. Improving productivity of concrete batching and production has been the continuous striving force behind numerous studies and equipment improvement techniques in the construction industry (Elazouni, 1997; Sawhney, 2003; Cheng, 2016; Seeman, 2016*).* Continuous monitoring and control is also an essential ingredient towards understanding key issues hampering productivity. Productivity translates the input directly into cost savings and profitability (Proverbs *et al.,* 1998).

India today is a thriving economy undergoing rapid infrastructural growth. This growth translates to a massive increase in large and multifaceted complex projects -high rise towers, metros, city complexes, smart cities, elevated corridors, factory projects to name a few. India's construction market is estimated to be almost double that of China by 2030 (Global Construction Report 2030, GCP, Oxford Economics, Mazloumian *et al.,*2015). A staggering figure of 165 million more people will be added to India's population by 2030 with Delhi itself adding another 10.4 million people to become the world's second-largest city. The success and functionality of any project are primarily dependent on its concreting operations, hence improving their effectivity and productivity acts as a vital factor towards determining the project success. According to Mishra (2012), if the right kind of maintenance is not chosen, then it may lead to over maintenance or under maintenance which might increase the cost and reduce the productivity. Therefore, the cost-effective and right maintenance at the right time will boost the productivity of a system by reducing the total breakdown time and by reducing the frequency of breakdowns.

2. Objective and scope

The primary objective of this study is to calculate system reliability and analyze the factors which affect the time to failure of a concrete batching plant system consisting of two batching plants with a fleet of four transit mixers. A model that will provide a mathematical relationship and provide a tool for failure forecasting is subsequently developed with an acceptable level of accuracy.

3. Failure data modeling concepts

Maintenance is a support group function which is essential to support the production-related processes. Frequent breakdowns in the equipment of the production line affect the overall productivity. The usage of maintenance differs among the companies. Maintenance is of three categories: preventive, corrective and predictive maintenance.

One of the essential strategies to carry out effective and efficient maintenance is forecasting the breakdown patterns of the machines. The two critical aspects of the maintenance capacity are the number of people involved in the maintenance and the skill set of those people to carry out the maintenance activities (Daya *et al*., 2009). The breakdowns are highly uncertain in nature and hence the corrective maintenance load and higher repair time, and due to this uncertainty, the forecasting of the breakdown of the machines are essential (Daya *et al*., 2009). There are two approaches on which the forecasting is based on. One is quantitative data, and the other one is qualitative data. Qualitative data is collected in the form of interviews and expert personnel opinion, and this is done when the historical data on breakdowns cannot be collected for the machine. On the other hand, the quantitative data approach is used when this historical data on the machines are available. The forecasting model could be built by using this quantitative data. The following steps are suggested when developing a quantitative forecasting model (Daya *et al*., 2009):

- Define the variables and identify the causality
- Collect and validate the data
- Locate significant trends and seasonality
- Propose different forecasting models
- Validate the models and select the best one
- Improve its performance

MTBF: Mean Time Between Failure is defined as the average time between two successive failures.
There are two methods for determining the value of MTBF (Rahman and Kadirgama, 2009):
1. Estimate MTBF: The value of MTBF could be found from the historical data.
2. Predict MTBF: This method is used when the historical data is not available. The value of MTBF is found out based on the reliability design of the system.

$$MTBF = \frac{1}{Failure} = \frac{Total\ running\ time\ during\ the\ period\ of\ investigation}{Total\ number\ of\ failures\ within\ the\ system}$$

…...**Equation 1**

$$MTBF = MTTF + MTTR$$

……**Equation 2**

MTTR: Mean Time to Repair (Average amount of Time the equipment has spent in the workshop/repair yard)
MTTF: Mean Time to Failure (Ratio between number of total hours of service of all equipment to the number of equipment.

4. Research Methodology

A three-phase methodology was used to develop a failure modeling tool to forecast the next failure of the concreting equipment (batching plants, transit mixers, boom placers). Primary data was collected from the construction site (New Hot Strip Mill, Rourkela) with breakdown hours, time to failure, daily concrete consumption and time to repair as the parameters. From this data, the Mean Time Between Failure(MTBF), Mean Time to Repair(MTTR) and Mean Time to Failure(MTTF) is calculated as given in Equation 1 and 2. The reliability of the concreting system can be calculated utilizing the "*k out of n*" algorithm with the assumption that minimum one concrete batching plant and two transit mixers need to be in working condition for the site to continue its operations smoothly. Now, ANOVA (analysis of variance) is performed to determine the interdependent factors and then choose suitable dependent and independent variables and create a multivariable regression model. Validation of the model can be done with F-test, t-test and ANOVA analysis to test the goodness of fit, adequate sampling, and other necessary parameters. Numerical relationships are obtained to express time to failure as a function of cumulative time to repair and cumulative concrete produced for various concreting equipment utilized on site. The third phase consists of interpretation of the results found and significance of results obtained and their practical implications. This model will provide an invaluable tool to site officials to allocate necessary resources based on future concrete batching plant failures and devise effective maintenance strategies to minimize such failures.

5. Analysis: Reliability of the System (k out of n method)

5.1 Concrete Batching System

The Batching Plant System can be thought of as a 1 out of 2 systems. We shall apply the k out of n method to calculate the overall system reliability for the batching plant only as given by the Barlow and Headman Algorithm. From data collected at the site, it was observed that Batching Plant 1(BP01) had 3164 working hours out of which it was out of service for 34 hours; whereas Batching Plant 2(BP02) had 2584 working hours out of which it was out of service for 31 hours due to break down.
Hence probability of failure of BP01=34/3164=0.011
Reliability of BP01=1-0.011=0.989
the probability of failure of BP02=31/2684=0.012
Reliability of BP02=31/2864=0.988
The probabilities of failure and their individual reliabilities are given in Table 1.

Table 1: Probabilities of Failure and Reliabilities of BP01 and BP02

		BP01	BP02
R	Reliability	0.989	0.988
(1-R)	Failure	0.011	0.012

Since this is a 1 out of 2 combinations only one failure is allowed which allows for the following cases:
Case 1: Both Batching Plants in working condition
Case 2: Either of the Batching plants in working condition.
Hence the reliability of the batching plant system will be:
$\mathbf{R_{BP}=R_1 R_2+ (1-R_1)\, R_2+(1-R_2)\, R_1}$ **…………. Equation 3**
R_{BP}= Overall Reliability of the concrete batching plant system.
R_1= Reliability of concrete batching plant 1.
R_2= Reliability of concrete batching plant 2.
The reliability of the batching plant system has been calculated in Table 2.

Table 2: Analysis of Various Cases

Cases	*Both Batching Plants Working*	*Only 1 Batching Plant Working*
	0.977	0.012
		0.011
	Total reliability of the system	**0.999**

5.2 Transit Mixer System

There are 4 transit mixers available at the site of which two must always be in working condition to ensure the smooth running of concreting operations. Hence this system can be thought of as a 2 out of 4 system. We shall apply the k out of n method to calculate the overall system reliability for the transit mixer system. From data collected at the site, it was observed that Transit Mixer 1(TM01**)** had 2650 working hours out of which it was out of service for 510 hours; whereas Transit Mixer 2(TM02) had 2868 working hours out of which it was out of service for 218 hours due to break down, Transit Mixer 3(TM03) had 2823 working hours with 162 breakdown hours,Transit Mixer 4(TM04) had 518 breakdown hours among a total of 2428 working hours.
Hence, probability of failure of TM01 =510/2650=0.011
Reliability of TM01=1-0.011= 0.808
Similarly, we calculate the values for TM02, TM03, TM04 and summarize the contents of Table 3 given below.

Table 3: Probabilities of Failure and Reliabilities of BP01 and BP02

		TM01	TM02	TM03	TM04
R	Reliability	0.808	0.924	0.943	0.766
(1-R)	Failure	0.192	0.076	0.057	0.234

Since this is a 2 out of 4 combinations only one failure is allowed which allows for the following cases:
Case 1: All four transit mixers working
Case 2: Only three transit mixers in working condition
Case 3: Only two transit mixers in working condition
Hence the overall reliability of the system will be:

$$\mathbf{R_{TM}=R_1R_2R_3R_4+(1-R_1)R_2R_3R_4+R_1(1-R_2)R_3R_4+R_1R_2(1-R_3)R_4+R_1R_2R_3(1-R_4)+(1-R_1)(1-R_2)R_3R_4+(1-R_1)R_2(1-R_3)R_4+(1-R_1)R_2R_3(1-R_4)+R_1(1-R_2)(1-R_3)R_4+R_1(1-R_2)R_3(1-R_4)+R_1R_2(1-R_3)(1-R_4)}$$

…. Equation 3

R_{TM}= Overall Reliability of the transit mixer system.
R_1= Reliability of transit mixer 1.
R_2= Reliability of transit mixer 2.
R_3= Reliability of transit mixer 3.
R_4= Reliability of transit mixer 4.

Table 4: Analysis of Various Cases

Cases	***All four transit mixers working***	***Only three transit mixers in working condition***	***Only two transit mixers in working condition***
	0.539	**0.128**	**0.011**
		0.044	**0.008**
		0.033	**0.039**
		0.165	**0.003**
			0.014
			0.010
	Total Reliability of the Transit Mixer System		**0.993**

5.3 Overall Reliability of the Concreting System

Since the concrete batching plant system and the transit mixer system are linked serially, the overall reliability of the concreting system can be calculated as $R_c=R_{BP}$ X R_{TM} = 0.999 X 0.993 = 0.992 or 99.2%.

R_c= Reliability of the Concreting System.

From "Nines" chart for "three nines," we obtain that the system will have a mean downtime of 8.76 hours per year, equivalent to 1.44 minutes of downtime per day. This result is an acceptable level of reliability for a high variability operation like concreting and shows efficient site management.

5.4 Development of Regression Models

From the raw data obtained at the site, the following Table 5 is formulated to calculate the Mean Time to Failure, Mean Time to Repair as given in Equations 1 and 2. Consequently one can get a brief idea as to what parameters are responsible for affecting the breakdown of an equipment.

Table 5: Calculation of MTBF, MTTR, Analysis of Batching Plant 1

No. of breakdowns	*Time to Failure*	*Time Between Failure*	*Cumulative MTBF*	*Cumulative MTTR*	*Cumulative Production Quantity (in cum.)*
1	**219.00**	**219.00**	**219.00**	**3.00**	**4706.26**
2	**596.00**	**377.00**	**298.00**	**6.50**	**21243.09**
3	**612.00**	**16.00**	**204.00**	**9.00**	**29222.37**
4	**3123.00**	**2511.00**	**780.75**	**8.20**	**34090.80**
5	**3222.00**	**99.00**	**644.40**	**9.20**	**53564.51**
6	**6408.00**	**3186.00**	**1068.00**	**10.20**	**58432.94**
7	**6442.00**	**34.00**	**920.29**	**10.80**	**68169.79**
8	**6564.00**	**122.00**	**820.50**	**11.40**	**73038.22**

Now a simple correlation analysis, as given in Table 6, shall be performed to determine which parameters are strongly linked with each other and to identify the dependent and independent variables for regression analysis. This analysis will give us a basic idea towards the formulation of the final model.

Table 6: Correlation table for Batching Plant 1

	No. of breakdowns	**Time to Failure**	**Time Between Failure**	**Cumulative MTBF**	**Time to Repair**	**Cumulative MTTR**	**Cumulative Production Qty (in cum.)**
No. of breakdowns	1.000						
Time to Failure	0.955	1.000					
Time Between Failure	0.108	0.306	1.000				
Cumulative MTBF	0.846	0.942	0.553	1.000			
Time to Repair	0.796	0.714	0.082	0.654	1.000		
Cumulative MTTR	0.911	0.812	0.123	0.725	0.887	1.000	
Cum. Production Qty (in cum.)	0.989	0.934	0.078	0.831	0.844	0.932	1.000

From correlation table (Table 6) for Batching plant 1, a strong positive correlation is obtained between Time to failure and Cumulative Production Quantity (=0.934), between Cumulative Mean Time Between Failure(MTBF) and Cumulative Production Quantity (=0.831), Cumulative Production Quantity and Cumulative Mean Time to Repair(MTTR) (=0.932), Cumulative MTBF and Time to Failure (=0.942), Cumulative Mean Time to Repair and Time to Failure (=0.812),Number of Breakdowns with Time to Failure (=0.955),Cumulative MTTR(=0.911),Cumulative Production Quantity(=0.989). Hence, Time to Failure is chosen as the dependent variable and Cumulative MTTR and Cumulative Production Quantity as independent variables to perform a multivariable regression analysis and obtain a failure model. Now, an ANOVA (Analysis of Variance) analysis, as given in Table 7, is performed with the following hypothesis:

Let, H_0 = Hypothesis that cumulative MTTR, cumulative production quantity does not affect time to failure

H_a = Hypothesis that cumulative MTTR, cumulative production quantity affect time to failure

Table 7: ANOVA Analysis for Batching Plant 1
(Dependent Variable: - Time to Failure; Independent Variables: -Cum. MTTR, Cum. Prod. Qty.)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	48658481	16219494	22.050	0.006
Residual	5	5516753	1103351		
Total	8	54175234			

From ANOVA analysis given in Table 7, we obtain the total degrees of freedom(n-1) as 8, the regression degree of freedom(k) as 5 and residual degree of freedom(n-k-1) as 3.The regression sum of squares(SSR) is obtained as 48658481 and the sum of squared errors of prediction (SSE) is obtained as 5516753 with the total sum of squares or total variability(SST) to be 54175234.The mean sum of residuals(MSR) is obtained as 16219494, and the mean sum of errors(MSE) obtained is 1103351 From this we obtain the value of F^*=22.05033 which is higher than F(0.95,1,6)=5.99[from F-table]. Hence H_a holds which means there is a definite relationship between Time to Failure on Cumulative Time to Repair and Cumulative Concrete Produced for Batching Plant 1. Now we perform multivariable regression model taking Time to Failure as a function of cumulative time to repair and cumulative concrete produced. A confidence limit of 95% was taken for all the above calculations. The obtained coefficient of determination R^2=0.8981 with a standard error of 2.742 and the regression equation obtained is:

$$T_f = 645.104 + 0.118C_p - 455.047T_r \qquad \text{………… } \textbf{Equation 4}$$

where, T_f = Time to Failure
C_p = Cumulative Concrete Produced
C_t = Cumulative Concrete Transported
T_{ry} = Time to Repair

We shall repeat the procedure with the data obtained from Batching Plant 2, Transit Mixer 1(TM01), Transit Mixer 2(TM02), Transit Mixer 3(TM03), Transit Mixer 4(TM04). The comprehensive list of concrete equipment studied, their regression model equations with standard errors and coefficient of determination along with F-test values and significance values are summarized in Table 8 below.

Table 8: Summary of Regression Analysis of Concreting Equipment

Equipment Name	Capacity	Regression Equation	R^2	Standard error	$F \le F^*$	Significance value(p<0.05)
Concrete Batching Plant 1	30 m^3/hr	$T_f = 645.104 + 0.118C_p - 455.047T_r$	0.898	2.742	F^*=22.05033 F(0.95,1,6)=5.99	0.006
Concrete Batching Plant 2	30 m^3/hr	$T_f = 92.592 + 0.086C_p - 51.186T_r$	0.996	82.981	F^*=3467.409 F(0.95,1,6)=5.99	3.96443E-16

Transit Mixer 1	**6 m^3**	**$T_f = 86.912 + 0.58C_t - 9.821\ T_r$**	**0.999**	**2.741**	**F^*=303631.7 F(0.95,2,2)=19**	**3.29345E-06**
Transit Mixer 2	**6 m^3**	**$T_f = 87.173 + 0.591C_t + 3.742T_r$**	**0.996**	**63.274**	**F^*=521.284 F(0.95,1,10)= 4.96**	**7.74014E-11**
Transit Mixer 3	**6 m^3**	**$T_f = 230.520 + 0.635C_t - 28.230T_r$**	**0.993**	**71.300**	**F^*= 844.972 F(0.95,1,11) =4.82**	**9.09632E-13**
Transit Mixer 4	**6 m^3**	**$T_f = -329.112 + 0.330C_t + 3.639T_r$**	**0.993**	**95.267**	**F^*=521.6566 F(0.95,1,4)=5.96**	**1.46E-05**

6. Discussion and Conclusion

It is found that although the availability of Batching Plant 1(=86.99%) is higher, its productivity (24.727%) is lower than that of Batching Plant 2 (availability=73.08%; productivity=29.939%). This is due to the higher failure rate of Batching Plant 1 (=0.002) as compared to Batching Plant 2(=0.001) and exhaustion of its useful service life. Also, its overall equipment efficiency could also be less which can only be verified by further analysis in the future. From the overall reliability of the system, we find that the total reliability of the overall concreting system is found to be around 99.2% which translates to an effective downtime of 8.76 hours per year of the overall system. This percentage is a relatively acceptable level of reliability for a high variability operation like concreting and shows efficient site management. What is noteworthy is that the greater availability of a construction equipment does not guarantee a higher productivity as evidenced in this case study. Availability was calculated as the ratio between actual working hours and total working hours, whereas productivity was calculated as the ratio between actual quantity produced to that given in the specification of the equipment. A value of 24.727% and 29.939% suggests that the productivity output of the batching plants is quite low and better management and maintenance is necessary to improve its productivity. From the regression analysis of all the concreting equipment separately, it can be concluded that there is a significant relationship between Time to Failure on cumulative concrete produced/transported and cumulative mean time to repair. The value of R^2 for all the linear regression models was found to be within the range of 0.896 to 0.996 which suggests that the models accurately describe the hypothesized relationship. Also, the goodness of fit tests is satisfied as verified by the f-test performed on all the models. Furthermore, the significance value of all models is well below 0.05 which suggests that we can safely accept our hypothesis. To obtain a generalized equation rigorous data analysis from multiple sites is necessary, but there are specific barriers to such data collection since contractors and construction firms are usually hesitant sharing the breakdown data of their equipment to hide inefficient practices. It is interesting to note that while the cumulative time to repair had a negative coefficient in 50% of the cases, the cumulative concrete produced/transported always had a positive coefficient. This seems to suggest that while in half the cases a significant amount of time spent in the yard resulted in improvement of the machine and lowered frequency of breakdown, but the other half had entirely different results. Hence the subjective factors like mechanic skill, maintenance strategy followed, quality of spare parts, yard infrastructure does play a crucial role in determining the time to failure of the concreting equipment.

In this analysis, we only consider quantifiable factors for which data was available. There are many more factors such as operator skill, quality of raw materials, site conditions, climatic conditions which also affect the time to failure but are challenging to quantify numerically. Further research can be done to quantify them through questionnaire survey and inculcate them in the model.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

The Dilemma of Pricing Against the Backdrop of the Chance/Risk Ratio

Christian Hofstadler
(Professor, Graz University of Technology, Graz, Styria, Austria)

Markus Kummer
(Project Assistant, Graz University of Technology, Graz, Styria, Austria)

Abstract
Calculating construction costs and times is one of the most important and demanding tasks in construction management and economics. Valid data and information is constantly being sought for labor consumption rates, output values, productivity levels, material consumption, quantities in stock, number of transport cycles, and cost and time parameters that must be estimated and/or calculated *ex ante*. Ultimately, final cost and time parameters are determined on the basis of such considerations and calculations. *Ex post* and/or *inter actio* analyses are performed to check if actual values achieved in the construction phase are identical to the target values. In an ideal scenario, the productivity level would be higher and/or material consumption or equipment utilization lower than originally planned. However, the chances that calculated assumptions are exceeded in a positive sense are also associated with risks of non-compliance in a negative sense.
Accurate figures must be stated or submitted at the end of any analysis. These depend on the complexity of the building or structure and on the conditions prevailing at the actual work stages and rely on more or less uncertain input data. One possible solution to this issue is to consider ranges that can deliver final conclusions on determined values. Applying probabilistic calculation methods appears to be useful to systematically consider ranges in input parameters. Key outcomes of probabilistic calculations include histograms derived from (numerical) simulations. These histograms are used to directly capture the chance/risk ratio relative to a specific (selected) value.
This paper outlines the dilemma of pricing and deals with the issue of viable bid prices in relation to the chance/risk ratio.

Keywords
management of chances and risks; chance; risk; Monte Carlo simulation; chance/risk ratio; costing; histogram

1. From Costing to Price

Irrespective of the method chosen to determine costs and prices, any bid submission will require a final and binding bid price. Steps to achieve this goal include estimates and/or (even better) calculations (see Fig. 1). Estimates and calculations can be either qualified or unqualified depending on the thoroughness of investigating boundary conditions and of the documentation provided, as well as the experience of the people to whom relevant works were contracted. Time is also a crucial factor when it comes to the quality standard of determining values. Irrespective of the chosen path, values must ultimately be stated for costs, prices, quantities, times etc. In so doing, working with ranges enables easier decision-making. Furthermore, it is highly beneficial to know the chance/risk ratio associated with the selected value.

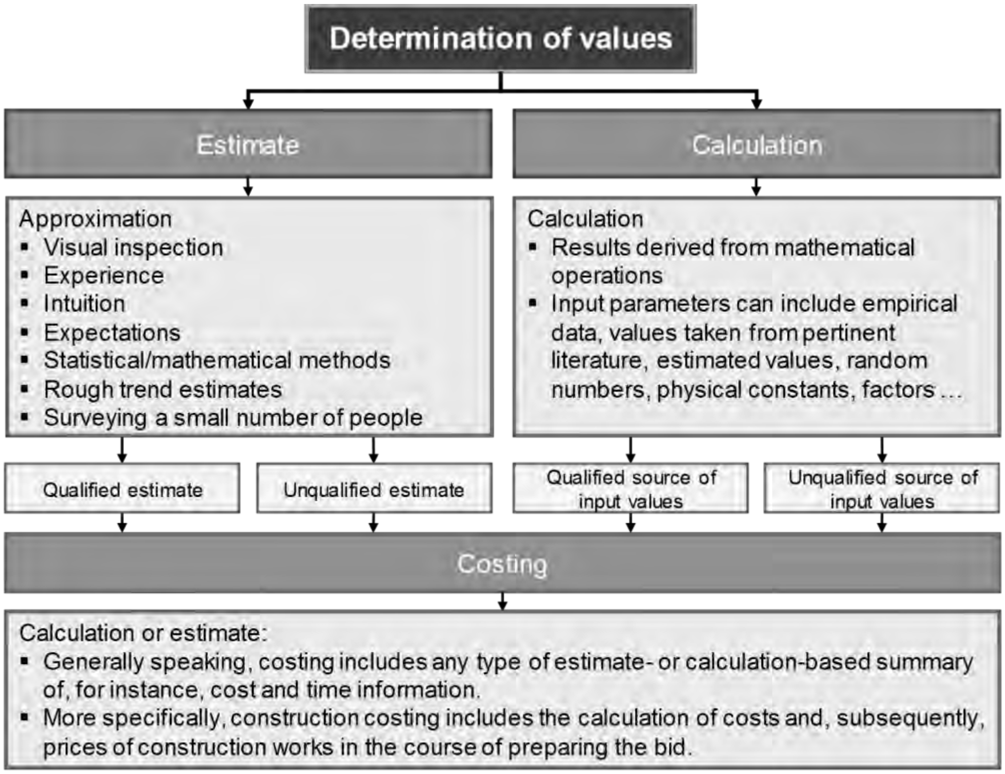

Figure 1: Options for determining cost and price values – estimates and calculations

From a mathematical point of view, the probability for the agreed (selected) bid price to be exactly identical to the invoiced total (even to the last decimal place) is zero. As we all know, the actual construction phase intervenes between the bid price and the invoiced total. At this stage, forecast circumstances and conditions are replaced with actual conditions under which work is performed. Moreover, changes to quantities and modified or additional works cause a difference between the price at which the contract was awarded and the final invoiced total (including all additional cost claims and expert, legal or court fees, if applicable). A low bid price negotiated by the principal or client on the market need not necessarily be equivalent to a similarly low level of the invoiced total. According to John Ruskin and others, at a low contract price, the client cannot expect a high quality standard to be implemented within a short construction period and without disruptions.

A zero-base costing exercise makes it possible to efficiently proceed from costing to pricing. This exercise requires expected values of calculation parameters (labor consumption rates, output values, quantities, material prices, equipment prices etc.) to be determined under the assumption of full cost coverage, excluding speculative elements (Oberndorfer and Jodl, 2001). The resulting values can then be used to derive figures for unit and item prices, and ultimately for the bid price.

However, this deterministic approach does not enable conclusions with respect to the probability of over- or underrunning target values. As is generally known, the magnitude of selected expected values depends on a number of factors, including experience, level of knowledge, attitude towards risks, analytical depth, details provided by the client/principal, and on the assessment of the complexity of the construction project and the proposed production system. Besides choosing expected values, it is thus useful to define ranges combined with distribution functions for key calculation parameters. This method enables the generation of histograms for each unit price, each item and, ultimately, for the bid price after completion of a probabilistic calculation (applying Monte Carlo simulations). These histograms make it possible to derive chance/risk ratios on the basis of selected individual figures.

2. Situational Analysis of the Significance of Probability in Construction Management and Economics

Probabilities are required for taking stock of what happened in the past as well as for forecasts of what will (trends) or could (assumptions) happen in the future. Statements with respect to probabilities are of major significance for all project phases and stakeholders as well as for decision-making during court proceedings. How probable is it for the client to achieve all goals defined for the proposed construction project? The answer to this question essentially depends on how the client, and its agents, comply with their obligation to cooperate in respect of enabling accurate planning and specification and ensuring a responsible contract award. If these efforts actually result in awarding the contract to the best bidder, there is an overwhelming (or high?) probability for the defined targets to be achieved. Conversely, this situation is associated with the favorable (and desirable) consequence of a reduction in the probability of occurrence of process disruptions and additional costs.

The probability of occurrence of forecasts is particularly important when it comes to estimating or calculating values that are used in costing exercises. *Ex post* considerations heavily rely on the aspect of probability when evaluating the documentation of actual construction activity. *Inter actio* analyses are performed during the construction phase and use actual values based on trend analyses to investigate the probability for targets to be achieved with respect to time, cost, quality standards and quantities.
Ex ante considerations rely on existing (disclosed) information and are merged with experience and historical data gathered from similar projects to be fed into forecasts of future events.

The probability for information to be accurate is highly relevant to both the client and the contractor. Prior to entering into the contract, this mainly involves the ability to determine the costs of works to be performed, and thus the transfer of risks and comparability of bids. The client must carry out thorough investigations and analyses to support its quantity and quality parameters, the conditions under which work is to be performed etc. with a high probability (characterized by precision and accuracy). Likewise, the costing assumptions and approaches applied by the bidders should be associated with a high probability of occurrence such that they can be justified at least from a commercial viability point of view. Unit prices tailored to the type, shape and complexity of the specific building or structure that also consider the resulting requirements with respect to quality, quantity, weather, construction time and environmental conditions are associated with a very high probability of accuracy. The quality of the information provided by the client has a direct influence on the quality of the information provided by the bidders, provided a "level playing field" in terms of the competitive environment exists.

Simulations effectively visualize the probability of the information provided by the client. Fig. 2 shows a histogram to illustrate the distribution of the reinforcement ratio for a group of structural components. Input parameters include common reinforcement ratios based on historical data (primarily depending on the structural system, element geometry, acting loads, number/dimensions/shapes of fittings/blockouts/openings etc.) taken from previous projects and/or information supported by pertinent literature. These parameters are subsequently adjusted to the conditions specific to the project and calculated by dividing the amount of reinforcement [kg] by the concrete volume [m³]. Distribution functions (triangular distributions in the case at hand) were used for both reinforcement amounts and concrete volumes. The resulting histogram creates a basis for the client (*ex ante*) to derive reinforcement ratios in the absence of more precise calculations at the specification stage, as well as for *ex post* analyses for the bidder/contractor to assess the quality of client information and to perform costing exercises.

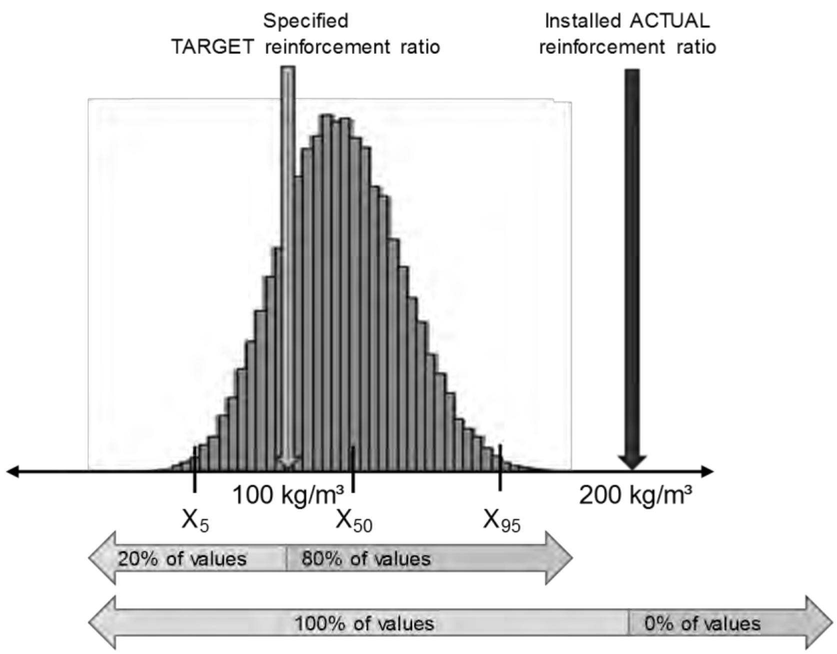

Figure 2: Probability of occurrence of the specified and installed reinforcement ratio

Fig. 2 uses reinforcing works to illustrate a situation in which the specified reinforcement ratio lies within a realistic range for a group of structural components (such as walls), whereas the actual (installed) reinforcement ratio lies outside this range. As shown in Fig. 2, the probability of occurrence of the installed reinforcement ratio is equal to 0%. In other words, there is a 100% probability for the contractor to assume a lower reinforcement ratio than actually installed on the basis of the information provided. Conversely, there is a zero probability of occurrence for the information that the client provided in the specification documents. The contractor adjusted its assumptions with respect to the bend shape distribution and mean rebar diameter to the specified reinforcement ratio. This is why the labor consumption rate that the contractor had accurately determined using the costing input parameters provided by the client can no longer correspond to the actual (installed) reinforcement ratio.

In the construction phase, it is important that contractors prepare and select their evidence (data, information, performance indicators, quantities etc.), for example for invoicing work performed and claiming additional costs (cause/effect relationships with temporal, spatial and resource-related references), such that their occurrence is associated with the (overwhelming, sufficient or high?) probability required for the specific case. In the interest of value retention, the chance/risk ratio derived from the costing exercise (i.e. the probability of over- or underrunning target values) should also be applied and adjusted to additional cost claims.

3. The Major Significance of the Reference Base

Any expectation of a positive or negative variance from the target essentially depends on the reference base. This means that any greater or smaller reference base for a labor consumption rate LCR [paid working hours divided by unit of quantity] will also result in comparatively greater or smaller probabilities of the actual labor consumption rate being lower than the defined reference base.

If, for instance, a histogram were derived for the labor consumption rate to be expected for reinforcing works, the median value could be used as a baseline for the costing exercise. In this scenario, the probability of under- or overrunning the selected labor consumption rate is equally distributed (50% for either option). In other words, the possibility that a risk in terms of a higher labor consumption rate materializes is equally high as the chance of generating a lower labor consumption rate during the construction phase. If, however, a reference base above the median is assumed, the chance/risk ratio will shift towards a positive variance from the target. The chance of generating a lower labor consumption rate is significantly greater than the risk of ending up with a higher labor consumption rate. Conversely, the risk will increase if the selected reference base of the labor consumption rate is lower than the median. There is a correspondingly small chance for generating a labor consumption rate, at the execution stage, that is lower than the already small reference base. The chance/risk ratio depends on the readiness of the company to take risks as well as on strategic considerations. In practice, contractors usually operate closer to the risks than to the chances because they have to apply a comparatively low reference base due to the existing competitive environment (Kummer and Hofstadler, 2013). Schubert (1971) already dealt with this topic and illustrated the selection of an appropriate reference base by referring to the example of earthmoving operations.

4. Bid Price and Winning the Bid

Defining or selecting the chance/risk ratio is a practice-driven approach that does not depend on any probabilistic target. The selection of the right chance/risk ratio will ultimately depend on the market price level or market situation, the readiness to take risks and further strategic considerations. Care should be taken to consider the chance/risk ratio both with respect to working profitably after the contract award and in relation to winning the bid (see Fig. 3).

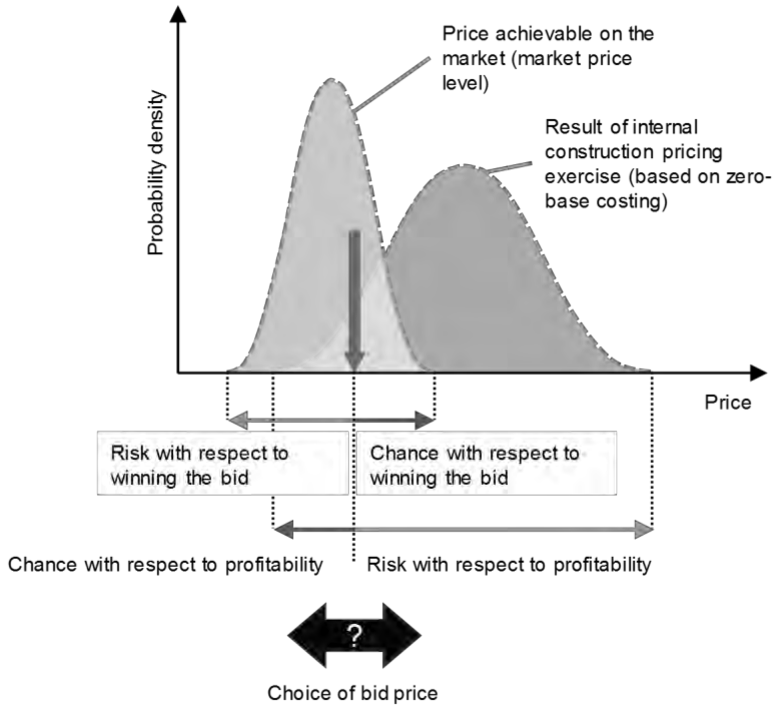

Figure 3: Choice of bid price with respect to working profitably and winning the bid (Kummer 2015)

Due to the nature of probabilistic calculations, it is not possible to accurately predict the outcomes of a construction project, such as with respect to actual construction times and costs. However, conclusions are possible in terms of the chance/risk ratio to be expected. For instance, each bidder arrives at its own estimates of the ranges of input parameters (such as cost, labor consumption rate and output values) when performing bid-related calculations. For one and the same project, this scenario results in different cost or price histograms with varying spreads, skewnesses, mean values etc. In other words, the estimated risk or chance is different for each bidder. These differences are due to varying assessments, different construction processes and methods, varying degrees of knowledge and expertise etc. At identical prices, bidders thus take various risks and enjoy different chances to adhere to, or underrun, the bid price in the construction phase.

When the bids are opened, each bidder will only see the prices quoted by the other bidders, without any information on how they arrived at the underlying values. However, any evaluation of bid prices based on a histogram and the corresponding probabilistic information enables judgment with respect to speculative elements or possible technological advantages. Any bidder that applies probabilistic calculation methods will thus be able to determine if it would have been able to cover its full cost based on its assumptions while executing the contract at the price of a cheaper competitor, and to identify the magnitude of the risk it would have taken.

5. The Dilemma of Pricing – Chance/Risk Behavior and Competitive Intensity

Bid prices are calculated using a zero-base costing exercise to enable a sound assessment of chances and risks with respect to bid pricing and final contract pricing. The subsequent definition of prices is based on the assumption that all production factors are utilized to a standard level and that no losses of productivity should occur from a contract pricing point of view. It is necessary to compute a histogram of the price distribution in the zero-base costing exercise to derive the corresponding chance/risk ratio. For this purpose, in the case of a unit price contract, costing assumptions must be supported by distribution functions wherever uncertainties are assumed in order to be able to calculate unit prices such that the price distribution histogram can be determined by a Monte Carlo simulation, for example.

Fig. 4 shows a continuous distribution where the horizontal axis represents the chance/risk ratio for calculated prices and the vertical axis represents probability density. Fig. 4 illustrates the existing competitive situation by a (randomly selected) dashed line with a gradient of about 20° (Scenario 1). Horizontal shifting of the straight line takes account of the existing competitive intensity (termed "Competitive intensity 1"). The fiercer the competition (many bidders, but only a few requests for proposals), the more the straight line has to be shifted toward the left, with the result that it is increasingly moving into the area of unviable prices[1]. At the same time, the risk potential increases, depicted by the arrow pointing to the right that runs parallel to the x-axis. Thus, there is a decreasing probability that a chance or opportunity can be utilized. It will then be highly improbable that the costs on which agreed prices are based are not overrun.

The slope of the straight line can be equated with a forecast with respect to the essential boundary conditions to costing/pricing associated with the specific construction project ("planning and specification quality = P+S 1"). The greater the accuracy of the calculated prices (as a result of fewer uncertainties in quantities and costing assumptions), the greater the slope of this straight line will be, corresponding to a comparatively tight spread between bid prices. This effect will also materialize if two bidders are farther apart from each other in terms of their chance/risk ratios (the vertical distance between Bidders A and B that represents the chance/risk behavior remains constant). In this example, Bidder B is significantly more willing to take risks compared to Bidder A. One possible explanation for this phenomenon could be that Bidder B urgently requires an additional contract to achieve its budgeted annual sales. Another reason could be that Bidder B wants to prevent Bidder A from entering this market segment by all means.

[1] The limit to unviable prices is identical to reaching the liquidity point. At this point, net revenues are equal to the total of fixed cash costs and variable costs.

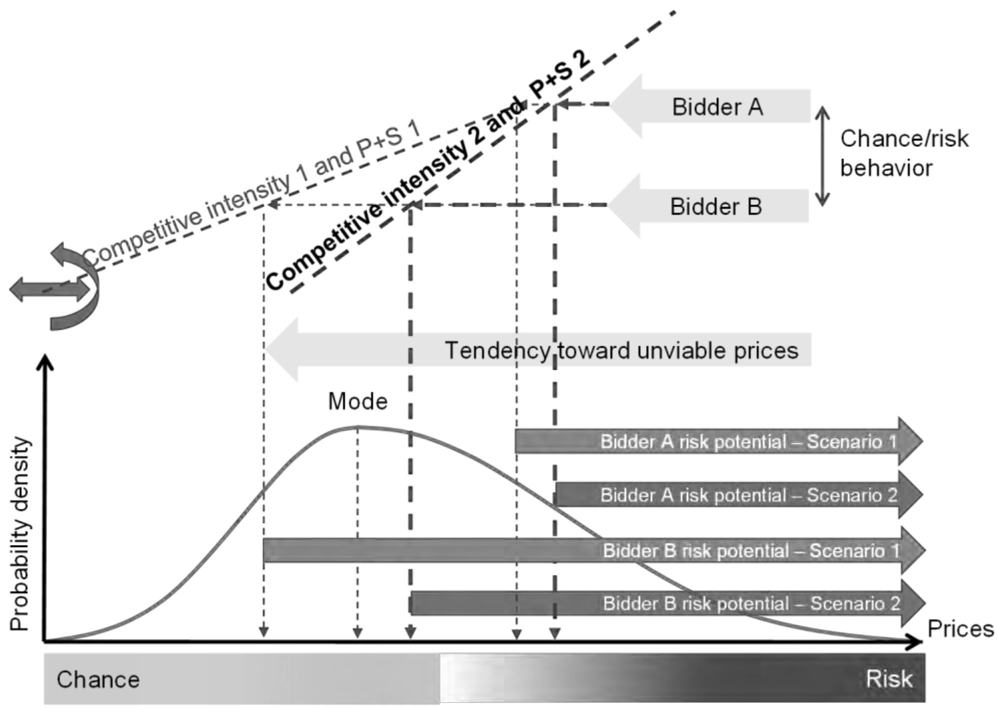

Figure 4: Chance and risk potentials depending on the competitive situation (mainly influenced by competitive intensity and quality of planning/specification) – Scenarios 1 and 2 (Hofstadler and Kummer 2017)

For comparison, Scenario 2 shown in Fig. 4 includes a second competitive intensity and planning and specification quality level whilst assuming an unchanged chance/risk behavior of Bidder A and Bidder B. The straight line was shifted to the right to a greater extent due to a competitive situation that is more favorable for the bidders (termed "Competitive intensity 2"). This scenario represents a lesser degree of competitive intensity, which should result in a tendency toward higher bid prices. Furthermore, the slope of the straight line was increased to consider a higher quality of planning and specification ("planning and specification quality = P+S 2") compared to Scenario 1. This shift reduces the probability of planning and specification errors and thus diminishes the potential for speculation. Overall, the prices quoted by Bidder A and Bidder B are located closer to each other. The bidders thus take less significant risks, and there is a higher probability for them to adhere to calculated construction costs in the project execution phase, as well as an increase in the chance potential for the subsequently selected contractor. For the client, this scenario brings the advantage of a high probability of the building or structure to be completed within the scheduled timeframe whilst complying with the agreed targets in terms of quality and budget.

There are limits to changing the slope of the straight line. Slopes of 0 and 90° are of a purely theoretical nature since they cannot occur in actual construction practice. A vertical straight line would correspond to a fully planned, seamlessly specified, contradiction-free construction project. Moreover, the parties to the contract would have to be in a position to access complete and accurate information, which is virtually impossible in the case of contracts for work in particular. There is thus only a theoretical possibility for a vertical straight line because the bidders would quote different bid prices for this scenario as well, although the documentation and information provided for costing and pricing purposes can be considered to be complete and free from contradictions. This phenomenon is mainly due to the unique nature of construction projects as well as to subjective differences in the assessment of costs in relation to production factors (internal production system). Bidders also arrive at different assessments of the complexity and circumstances of work to be performed (external production system), which is due to varying ways of handling information as well as to differing chance/risk affinities. Cases where construction projects are planned and specified in an entirely inappropriate manner do not (or hardly) occur in practice. Guidelines and standards exist that govern the minimum quality standard of planning and specification, which means that it is equally impossible to end up with a horizontal straight line in the diagram. However, an exceedingly poor quality of planning and specification will result in only a small slope of the straight line, and thus lead to a wider bid price spread. This phenomenon is mainly caused by an exceedingly large room for interpretation that may potentially result in major differences between the assumptions applied by the bidders. This scenario is thus associated with a high degree of asymmetrical information. Even if the results of the (zero-base) costing exercises performed by all bidders are very similar, strategic or speculative considerations may lead to huge differences in the quoted bid prices. Although Fig. 4 includes only an idealized scenario of the key mechanisms between competition, planning and specification accuracy, prices and chances/risks, it enables a very good overview of the economic relationships and interactions prevailing in construction management.

4. Conclusions

Any determination of costs and prices based on estimates and/or calculations will ultimately have to result in a final and binding bid price. Input parameters or costing approaches are associated with comparatively big or small uncertainties depending on the scope and quality of available information and tender documents as well as on the experience and the time available for submitting a bid. These uncertainties should be reflected in the costing exercise by means of probabilistic calculation methods (Monte Carlo simulations), and results should be shown in the form of histograms. It will then be crucial to select a value within the identified ranges that is associated with conclusions with respect to over- or underrun probabilities. The corresponding chance/risk ratio will also change depending on the selected reference base. This ratio can be utilized for both managing and verifying decisions; it can help ensure long-term profitability amidst a fierce competitive environment.

For pricing purposes, bidders should not only rely on their own costing exercise (so-called zero-base costing, i.e. full cost coverage without speculative elements). When selecting an appropriate reference base, such as the bid price, they should also consider the influence of the competitive environment and of the price that can be realistically achieved on the market. Bidders must differentiate their considerations of the chance/risk ratio in relation to winning the bid and working profitably and arrive at a balanced view of these two factors with regard to the chance/risk policy pursued by the company. For all stakeholders, it is essential that they are capable of stating their decisions or selected values relative to a specific chance/risk ratio. Only then will it be possible, both on the corporate and project level, for profits to outweigh losses in the long term, thus ensuring continued liquidity of the construction contractor.

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In-Depth Bid Assessment for Unit-Priced Contracts

Christian Hofstadler
(Professor, Graz University of Technology, Graz, Styria, Austria)

Abstract
Both at the design and specification stages and when assessing submitted bids, the client bears great responsibility for ensuring a high standard of workmanship, fair competition, economic efficiency, and the greatest possible benefit for management and operations. Public-sector clients use in-depth bid assessment as an effective tool to eliminate bids that are implausible or that bidders cannot sufficiently justify in related discussions. To ensure project success on all levels, it is crucial for the client to identify the chance/risk ratios associated with each of the bidders. Conversely, to ensure the continued existence and operation of its business, it is very important for the contractor to be aware of the chance/risk ratio on which the bid price is based. In either case, the selected baseline value determines the specific ratio of chances and risks. For reference purposes, the client can rely on cost estimates provided by experts, such as construction cost indicators adjusted to the specific region and project, whereas the contractor is in a position to apply full costing free of speculative elements (break-even costing).
This paper describes the models and calculations that enable a transparent breakdown of cost risks in the specification and award process. For this purpose, Monte Carlo simulations and associated histograms for the interpretation of results are used in order to systematically consider uncertainties and ranges of values in the bid assessment.

Keywords
Management of chances and risks; bid assessment; unit-priced contract; Monte Carlo simulation; chance/risk ratio; costing; histogram

1. Bid Price and Winning the Bid

Defining or selecting the chance/risk ratio is a practice-driven approach that does not depend on any probabilistic target. The selection of the right chance/risk ratio will ultimately depend on the market price level or market situation, the readiness to take risks, and further strategic considerations. Care should be taken to consider the chance/risk ratio both with respect to working profitably after the contract award and in relation to winning the bid (see Fig. 1).

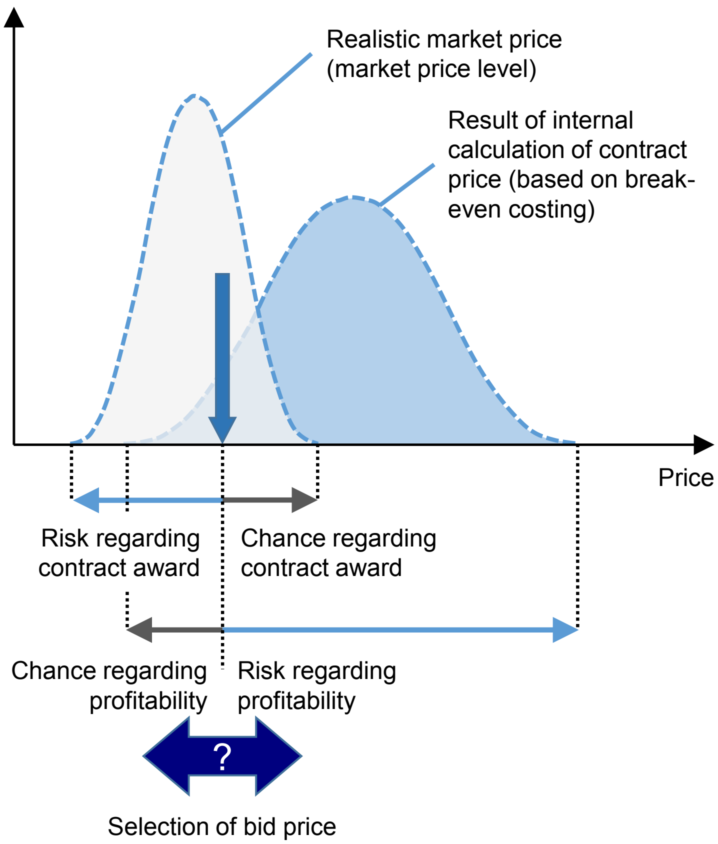

Figure 1: Selection of bid price with respect to working profitably and winning the bid (Kummer 2015)

2. Chance/Risk Ratio Relative to Pricing

Any results generated in the form of histograms enable conclusions regarding the chance/risk ratio for each of the selected deterministic values. We can thus determine the specific chance/risk ratio for items, work categories, and the selected bid price. In so doing, we use the calculation results of the break-even costing exercise as a reference. Histograms are generated for the calculation results relative to the unit price – through the input parameters partially/fully fraught with uncertainties. For final pricing purposes, the final unit price is entered as a deterministic value in the histogram, which makes the associated chance/risk ratio transparent for the specifier/decision-maker. This exercise can be repeated for each item within a single work category as part of a bottom-up analysis (see Fig. 2).
The bidder/contractor also needs to be aware of its cost histogram to be able to grant discounts or include markups. For instance, the influence of a 10% discount on the chance/risk ratio will vary depending on the curve of the histogram. If the histogram includes a very small spread, an exceedingly high discount may give rise to an intolerable risk because the chance to perform the work at an even lower price would decrease rapidly. Thus, in histograms with a small spread, percentage discounts relative to the price have a greater influence on the chance/risk ratio than in

the case of distributions with large spreads. Without knowing the distribution, no conclusion is possible as to whether the risk would still be tolerable after granting a discount or whether the new chance/risk ratio is in line with the chance/risk policy of the business.
Conversely, when starting from a chance/risk ratio, a reverse calculation can be performed to determine the maximum tolerable discount. For instance, if the contractor wants to deviate from the mean by up to one standard deviation for the purpose of preparing its bid, the discount permissible up to this specific chance/risk ratio can be identified.

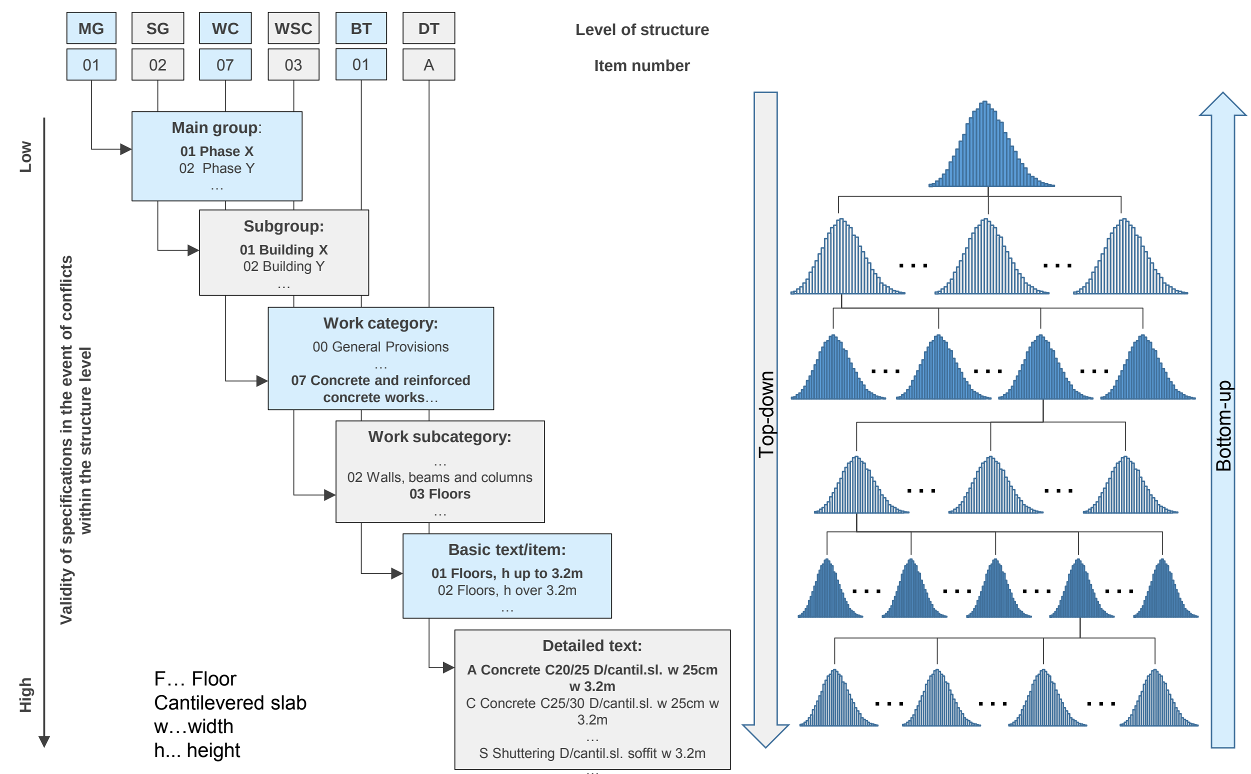

Figure 2: Top-down and bottom-up approach for selecting the basis relative to a bill of quantities

3. Systematic Consideration of Uncertainties in the Bid and Award Process

It is important for the client to be able to quantify future costs of construction works even though costs can still be influenced to a relatively large extent in early project phases – for two reasons: first, to intervene in, and adjust, the planning and design to the available budget; second, to quantify project funding and to be able to assess chances and risks.
Depending on the degree of design detail and project progress, various methods are available for calculating future costs of construction works, including commonly applied use- and building/structure-related methods that rely on cost indicators. Depending on the applied method, level of knowledge and specificity, a greater degree of detail can be achieved by refining the respective consideration or exercise.

The cost estimate is used to determine the cost for the contract award, as well as a basis for cost control (target/actual comparison with costing). It forms the basis for deciding upon the detailed design and award preparation. This costing exercise is performed prior to providing the bills of quantities, on the basis of the detailed design, building specifications, and schedule of work execution.

This paper includes a worked example to demonstrate how Monte Carlo simulations are used to account for uncertainties when performing calculations for the cost estimate. (Kummer and Hofstadler, 2013) The associated in-depth analysis involves any applicable ranges of item prices and provides the opportunity to subsequently correct items included in the bill of quantities prior to publishing the request for bids. Even before opening the bids, the client will thus be provided with an overview of possible bid price ranges.

The price histograms derived from the simulation are subsequently used for bid assessment purposes, thus enabling judgment as to whether the prices quoted by the bidders are plausible and/or to determine the chance/risk ratios associated with quoted prices.

4. In-Depth Bid Assessment

As part of the building specification, the bill of quantities is essential for the bidder/contractor to carry out costing and pricing exercises (but always in conjunction with the entire set of tender documents). The client must describe all conditions and circumstances of work performance in such a way that the bidder is in a position to prepare its bid on the basis of appropriate interpretation of the objective explanations contained in the documents.

Vis-à-vis the client, the contractor must justify all assumptions (i.e., costing assumptions and/or risks) made on the basis of the tender documents for the purpose of pricing and work execution, as well as all dispositions within its remit and the risks associated with the suppliers and subcontractors selected by the contractor.

According to the above process, the client usually prepares the bill of quantities, and the bidder performs the costing exercise for its bid and derives related assumptions. For instance, if the client blends several types of work for various structural components, trades, types of floor, rebar diameters etc. into a single item, and if the bases for the costing of these mixed items are not disclosed, the bidder is forced to make unsupported cost assumptions so as to be able to complete its costing exercise in the first place.

Any change in the proportions of the specified types of work "blended" in the single item in relation to the cost assumptions made by the bidder will also change the pricing structure, which may result in higher or lower costs relative to the bid price.

The building specification forms an essential basis for the contractor to be able to perform its costing and pricing exercises. Relative to the planned construction works, this means that specification details must be assessed or interpreted in line with how the bidder understands the explanations provided in the tender documents when objectively evaluating the situation or conditions. According to this approach, the bidder or entity performing the costing exercise should trust the documents provided, and will incorporate their content as well as the conditions for work performance communicated or expected in its costing and pricing.

In a unit-priced contract, unit prices and quantities are listed together with item prices, which are added up to get the total price. Not only an exceedingly low total price may indicate speculative elements; comparatively higher prices quoted by bidders can also include such components. The following sections outline how to systematically review unit prices when performing an in-depth bid assessment for a unit-priced contract.

4.1 Task

Using the rebar reinforcement specified for a construction project (i.e., an engineering structure), a bidder has quoted corresponding price components for wages and other items (see Fig. 3). At first glance, the unit price appears to be markedly low. In the next step, a breakdown is carried out to perform an in-depth assessment of the wage and other components. The wage component [€/t] results from multiplying the labor consumption rate [wh/t] with the mean wage price [€/wh]. Dividing the wage component [€/t] by the mean wage price of €40/wh quoted in the bid gives the associated labor consumption rate of 4 wh/t (see Fig. 3).
For the in-depth bid assessment, the labor consumption rate of 4 wh/t resulting from a reverse calculation from the bid is shown in a labor consumption rate histogram based on pertinent literature whilst considering existing uncertainties. This comparison subsequently reveals the risk the bidder has taken when submitting its bid and/or where its calculated labor consumption rate is located within the calculated range of plausible labor consumption rates.
Values confirmed by practitioners should be taken from pertinent literature (or benchmarks from site analyses or final costing exercises should be used) to arrive at a representative basis for the in-depth assessment.

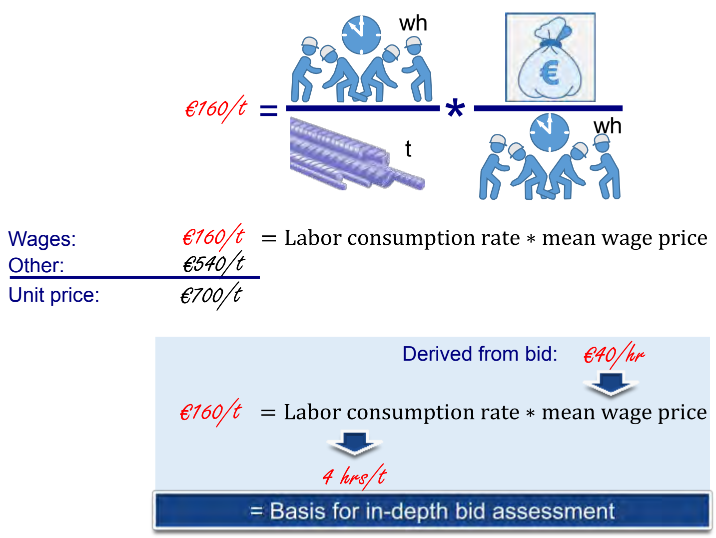

Figure 3: Calculation of the labor consumption rate from the wage component

4.2 Modeling

The definition of uncertain input parameters includes the quantity proportions of diameters, bend shape proportions, and labor consumption rates per diameter and bend shape. In the computation model, the mean wage price is included as a deterministic value (following from the quoted amount of €40/wh).

In the modeling exercise, quantity and bend shape proportions must be normalized to 100% to ensure that the simulation does not result in any over- or underrun of specified reinforcement ratios (the quantity used for the in-depth bid assessment is identical to the quantity stated in the bill of quantities).
To calculate the mixed labor consumption rate, the quantity proportion of each bar diameter is multiplied by the weighted bend shape proportions (i.e., straight, simple bend, and complex bend) and by the distribution functions (see triangle symbols included in Fig. 4). For each diameter and bend shape, this calculation step gives labor consumption rate proportions shown in histograms. The derived labor consumption rate proportions are then added up to form the histogram representing the mixed labor consumption rate. This histogram is used as a reference to check the plausibility of the labor consumption rate included in the bid price. This comparison also requires a reverse calculation of the quoted mixed labor consumption rate from the unit price and/or from the wage component (Fig. 4 includes arrow symbols for deterministic parameters). For this purpose, the wage component [€/t] is divided by the mean wage price. The resulting deterministic mixed labor consumption rate included in the bid (i.e. 4 wh/t) can then be used to check appropriateness and plausibility.

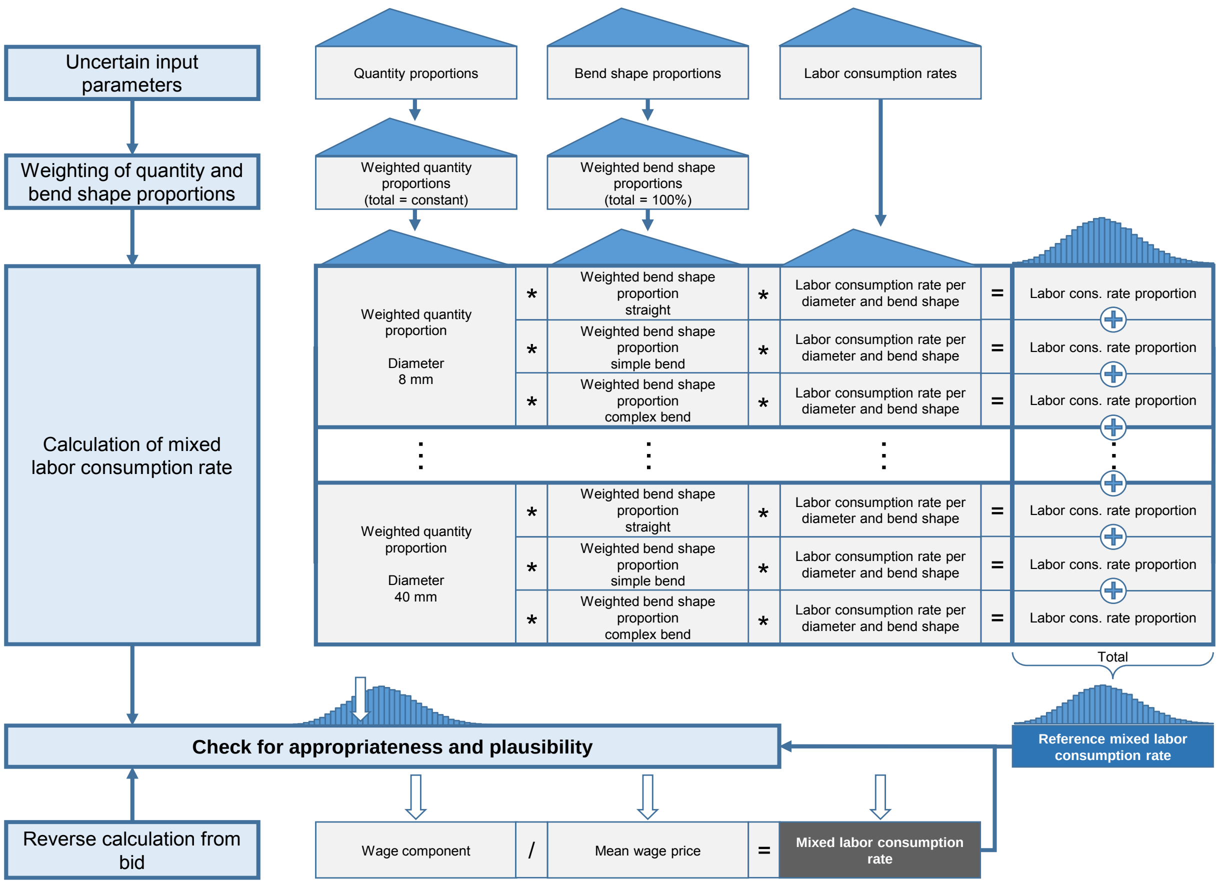

Figure 4: Schematic representation of the modeling sequence (Hofstadler and Kummer, 2017)

4.3 Calculation and Interpretation of Results

Fig. 5 depicts the histogram resulting from a Monte Carlo simulation performed to calculate the mixed labor consumption rate for reinforcing works in an engineering structure. In this histogram, the median amounts to 10.91 wh/t, whereas the X_5 quantile and the X_{95} quantile equal 10.40 wh/t and 11.47 wh/t, respectively. The X_5 quantile of 10.40 wh/t is used as a basis and 10% are deducted to define the minimum labor consumption rate for the assessed construction project. The marginal labor consumption rate of 9.36 wh/t determined in this calculation is identified as the absolute minimum in the course of the in-depth bid assessment. All bids quoting a labor consumption rate below 9.36 wh/t must thus be eliminated because there is a 0% probability of underrunning this labor consumption rate. This value is not achievable during actual construction work since higher labor consumption rates are achieved in 100% of real-world cases.

In the next step, the labor consumption rate of 4 wh/t used as a basis for the bid is compared with the range of plausible labor consumption rates. Fig. 6 also clearly visualizes the fact that this value lies considerably below the achievable range. The difference to the minimum amounts to approx. 57% [= (9.36 wh/t - 4 wh/t) / 9.36 wh/t * 100%)]. In other words, the limit for a plausible labor consumption rate is about 234% (= 9.36 wh/t / 4 wh/t * 100%) above the quoted labor consumption rate of 4 wh/t.

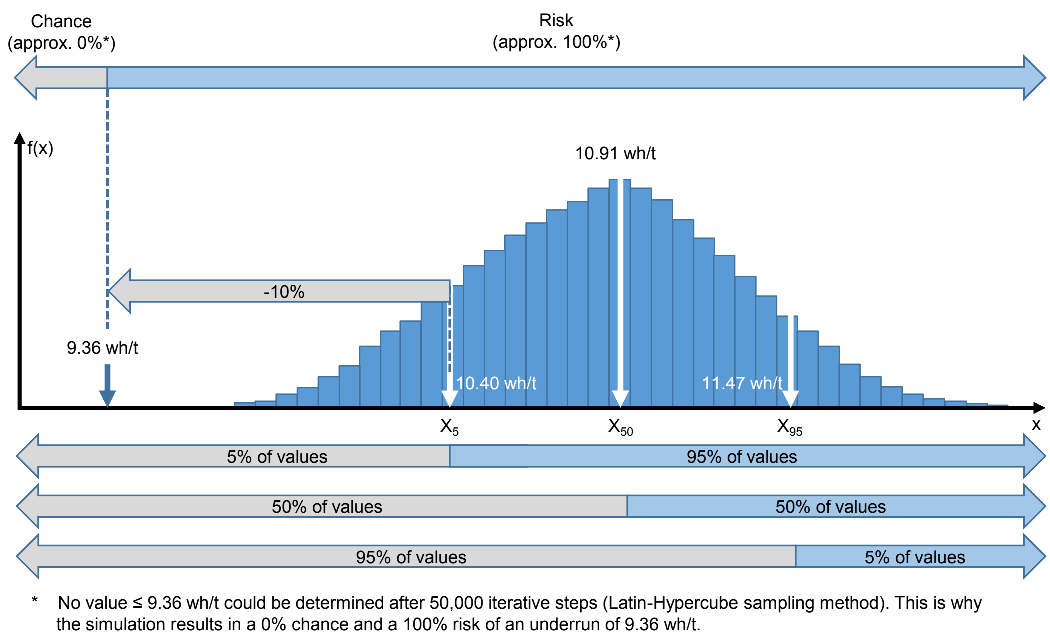

Figure 5: Distribution as a result of a Monte Carlo simulation performed to illustrate the determination of a minimum labor consumption rate for reinforcing works

This example demonstrates very clearly that the labor consumption rate, and thus the wage component, lie far outside the range of covering possible costs. The quoted price is thus inappropriate and lies significantly below the minimum price limit. The above labor

consumption rate (i.e., 4.00 wh/t) cannot be achieved even if assuming efficient construction management and economical business operations; it would not permit a high standard of workmanship, including liability for any defects.
In the case at hand, this exceedingly low price would put the liquidity of the business at risk, provided workers are paid wages in compliance with the law. At any rate, this bid clearly contradicts the principle of economic plausibility of prices.

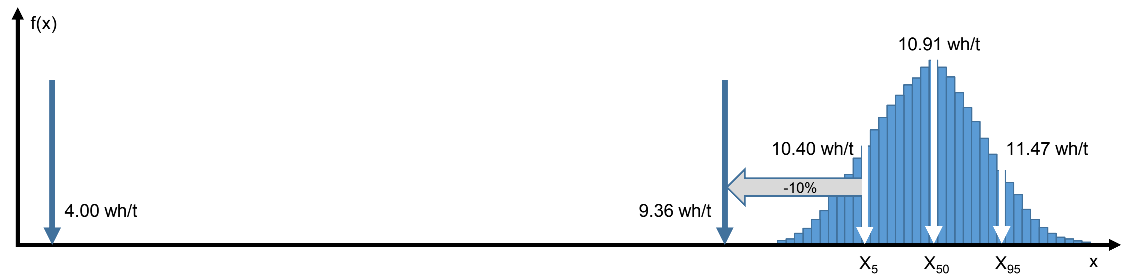

Figure 6: Distribution as a result of a Monte Carlo simulation performed to illustrate the determination of a minimum labor consumption rate for reinforcing works – comparison with the quoted labor consumption rate of 4 wh/t

According to the principle of economic plausibility, prices should at least cover primary costs/expenses such as wages and salaries, materials, equipment repairs and/or subcontracted services. These costs are largely variable; they are definitely incurred and cannot be earned through other works or services or construction projects. As is generally known, labor consumption rates determine the variable cost base and must thus be considered at an appropriate, profitable level in the wage component.
The unit price of €700/t quoted in this case (and particularly the wage component of €160/t) does not fully cover related costs because it is far below the plausible or justifiable variable cost base. Nor is the bidder in a position to explain this gap between the quoted price and the above-mentioned insufficient price in the course of a related discussion, which is why this bid must be disregarded.

5. Conclusions

For the client, the greatest benefit lies in the representative, plausible reference base for assessing the labor consumption rates determined in a reverse calculation from quoted unit prices. The client can thus ensure that it has followed a systematic approach that is sound both from a construction management/economics and legal point of view when conducting the in-depth bid assessment.
A minimum labor consumption rate specific to the building or structure and specification exists for any type of construction work. There is no way of working more quickly or productively because there are limits to the workload that can be imposed on employees, as well as manufacturing and technological limits to the other production factors, i.e. equipment and materials. Other influential factors that increase the labor consumption rate include the shape and

dimensions of structural components, and ambient and weather conditions. This situation inevitably causes labor consumption rates to lie (far) above the stated minimum depending on the specific project conditions.
If calculated labor consumption rates are greater than the minimum required in terms of construction management (including main and ancillary works, idle time, breaks, loss and distribution periods, and off-peak hours) that was determined applying the above method, related work items can be considered to be plausible whilst considering the specific requirements for work performance.
Adherence to this systematic approach (labor consumption rate = wage component divided by the mean wage price; subsequent comparison with the probabilistic minimum) in the course of assessing the bid for all major labor-intensive items can uncover wage and/or social dumping.
When evaluating the agreed compensation, the wage component must be considered independently of the "Other" item. This differentiation is necessary to separate labor-intensive work from equipment- and material-intensive types of work, thus preventing/reducing commingling of various bases for pricing. Analyzing the wage component makes it possible to identify calculated working hours for the entire building or structure, work categories, or individual items, depending on the aim of the analysis.
This principle is comparable to track and field sports, where, for example, times that are plausible (achievable) in a 100 meter race are subject to physical, biomechanical and medical limits – there is just no quicker way to finish. The same applies to construction management since any work requires a certain minimum consumption rate to be performed. It is not possible to assume fewer paid working hours even if only the generally assumed, average quality standard and characteristics are specified.
In conclusion, only bidders quoting plausible labor consumption rates should be considered for construction contracts in order to prevent wage and/or social dumping. In contrast, bids with exceedingly low prices and associated labor consumption rates below the minimum determined for a specific type of work should be disregarded. This approach would protect the construction industry in the country in which the project is to be completed against illegal practices whilst also enabling the award of contracts for projects to lawfully operating businesses posting employees there.

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Factors Influencing Productivity of Concreting Equipment in Indian Construction Projects

Abid Hasan
Ph.D. Candidate, University of South Australia, Adelaide, Australia
abid.hasan@mymail.unisa.edu.au

Kumar Neeraj Jha, Nihar Ranjan Sahoo, Arka Ghosh
Department of Civil Engineering, Indian Institute of Technology, New Delhi, Delhi, India
knjha@civil.iitd.ac.in, niharrsahoo15@gmail.com, Arka.Ghosh.cec16@civil.iitd.ac.in

Abstract
Equipment productivity plays a significant role in the sustainability of any construction organisation in this stiff competitive market. In developing countries, one of the main concerns on construction sites is low productivity of concreting equipment. Concreting equipment form the core equipment in most of the construction projects and the costs associated with the use of these equipment are usually high. As a result, low productivity of concreting equipment affects both schedule and cost. The purpose of this paper is to identify various factors that affect productivity of concreting equipment in construction projects, especially in developing countries such as India. A questionnaire survey was conducted among experienced professionals (managers and site engineers) from across the Indian construction industry. The study identified five key factors as: (1) *improper maintenance; (2) unskilled operator; (3) poor planning; (4) inefficient operator;* and *(5) lack of coordination among different crews.* The major findings also indicate that engineers and managers share a general perception of the factors affecting equipment productivity; however, differences do exist. The outcome of this paper will help in addressing the issue of low productivity of concreting equipment in construction projects.

Keywords
Concreting; productivity; construction equipment; Indian construction industry.

1. Introduction

The construction industry makes significant contribution to both economy and employment in both developed and developing countries (Arditi and Mochtar 2000, Deloitte 2014). Despite its high significance, many construction projects suffer from time delays and cost overrun (Sun and Meng, 2009). Iyer and Jha (2006) reported that 40% of 646 national projects in the Indian construction industry were approximately 40% behind schedule. Whereas, Ahsan and Gunawan (2010) compared the performance of international development projects in India, China, Bangladesh, and Thailand, and found that construction projects in India had the worst schedule performance. In a study by KPMG International (2013), 77% of the total executives interviewed from 165 engineering and construction companies around the world identified delays among the topmost reasons behind underperformance in construction projects.

In today's global economic conditions, improving productivity in the construction projects could eliminate time and cost overruns. It has become a key focus area over the last decade attributable to its strong potential in benefitting the construction industry. However, in a construction project, a large number of factors affect productivity and that there is a necessity to locate the most influential ones among them. In the developing construction markets such as India, low equipment productivity has remained one of the leading causes of delay in the completion of construction projects.

As per the data provided by statistics portal *Statista*, the consumption of cement and aggregates in India has gone up to 255 million metric tonnes and 1.7 billion metric tonnes respectively in the year 2015. These figures indicate the amount of concrete being used in developing nations due to the rapid pace of construction and infrastructure development. Although, a large number of researchers have provided their insights into the identification of factors affecting labour productivity (Hughes and Thorpe, 2014; Naoum, 2016), reasons behind low productivity of concreting equipment have not been explored in sufficient depth.

2. Literature Review

In comparison to studies related to labour-intensive projects, research on workflow management and factors that cause disruptions in equipment-intensive operations has not been as undertaken extensively (Choi and Minchin, 2006). Yi and Chan (2014) concluded that hourly output is the most reliable measurement of productivity for construction activities. This definition of equipment productivity also reveals that when the productivity rate decreases, the activity duration increases. When the duration increases, it will result in higher fuel consumption and higher emissions and thereby, damaging the environment (Hajji, 2015). Consequently, poor equipment productivity has also negative implications for the environment, in addition to cost and schedule overruns.

The researchers have identified issues such as old and obsolete construction equipment, insufficient number of tools, shortage of spare parts, improper service and maintenance, slack use of machinery, unavailability of consumables, poor equipment maintenance, slow equipment repairs, improperly maintenance of power tools, and inefficient operator as the most significant causes associated with construction equipment that lead to poor productivity in construction projects (Dai *et al*., 2007; Rivas *et al.,* 2011). Regarding equipment productivity in concreting operations, factors such as such as placing method, organisation and management, labour crew skills, pumping spaces, site congestion, and number of truck mixers available have been found significant (Anson and Wang, 1998; Zayed and Halpin, 2001).

Alwi (2003) found that logistic problems and site congestion were the two major causes associated with low equipment productivity in Indonesia. Moreover, operator's skill and training were also found to be among the key factors that negatively affect equipment productivity. Zayed and Nosair (2004) identified factors that cause a delay in the concreting operation and their effect on concreting equipment productivity and overall cost. The major factors affecting uncontrolled delays were availability of work front, job specifications, and weather conditions. Whereas, controlled delay factors included management conditions, skill of pouring crew, number of truck mixers, site conditions, and material supply system. Prasertrungruang and Hadikusumo (2009) studied efficient management and downtime consequences of equipment used in highway construction by taking into consideration factors like operational practice, maintenance management, equipment life, and training of equipment operators. The researchers found that variables affecting equipment productivity include machine availability rate, relationship among dealers and contractors, and equipment administration policies. The main reason for this research study is a perceived gap in the current body of knowledge in relation to concreting equipment productivity, especially in the context of developing countries such as India.

3. Research Method

The literature review helped in the identification of factors that affect the productivity of concreting equipment. In addition to the literature review, five pilot interviews with the project managers who had more than 16 years of experience, were also conducted to gain more insights into factors affecting productivity of concreting equipment. Finally, on the basis of literature review and subsequent discussion with the experts, a total of twenty-nine factors influencing the productivity of concreting equipment were identified in the context of the Indian construction industry. These factors were then structured into a questionnaire in two stages: first, a preliminary questionnaire was developed and pre-tested by a small group of four project managers to ensure that the questions were easily understood and correctly interpreted by the members of the population. Then, after a few amendments in the design of the questionnaire, a final questionnaire was developed for collecting responses from the construction management professionals working across the country.

For collecting the data, it was considered important to select the construction sites appropriately. Therefore, to develop a current and more generic understanding of the factors affecting concreting equipment, only those under-construction projects which had a project cost of more than \$10 million, were selected for this research. Moreover, to find out the common issues at the level of the industry and to minimise the bias in response, only one random project from a contractor was included while dropping out the other projects involving the same contractor. As a result, 11 construction projects out of 26 initially selected projects from the national capital region (NCR) and two adjoining states of India qualified for this research. These projects included: three housing projects, six power plant construction projects, and the remaining two were industrial projects. To receive the views from cross-organisations, responses were collected from both managers and site engineers.

A total of 130 questionnaire sets were initially distributed both by hard copy and via email. After four months of regular follow-up, 91 respondents returned the questionnaires, of which 82 were duly completed and therefore, formed the basis of this paper. The respondents included 39 managers and 43 site engineers. The response rate percentage was 63.1%, which is well accepted. Of these, 32 respondents were working on industrial projects whereas; balance 50 respondents were from building and infrastructure projects. The respondents' mean experience was 16 (standard deviation 8 years). Because of the high experience, the respondents can be considered suitable to answer the questionnaire. According to Vaus (2001), in the smaller size of samples, the quality of the responses would be considered to be highly reliable for the analysis if the respondents have relevant industry experiences and clear understanding of the questionnaires. Initially obtained in terms of a five-point Likert scale in which 1 represents strong disagreement and 5 represents strong agreement, responses were stored and analysed using the *Statistical Package for Social Sciences (SPSS)* software program. In order to determine the relative rank of each factor surveyed, the data collected were analysed using the Relative Importance Index (RII) technique (Fugar and Agyakwah-Baah, 2010). Before calculating RII for each factor, it was deemed necessary to test the reliability of the scale used. Hence, Cronbach's alpha coefficient (α) was calculated for the data set to determine the internal consistency and item correlation. Generally, a questionnaire with α-value of 0.7 is considered reliable (Field, 2009). The value of alpha was calculated to be 0.814, which is acceptable.

Each of the factors affecting the productivity was ranked on the basis of RII using the following formula:

$$\sum wA \text{ X } N \qquad (1)$$

where, w = weight assigned to each factor by the respondents and it ranges from 1 to 5; A is the highest weight (i.e., 5 in this case); and N = total number of respondents. The highest RII value indicates the most critical factor with rank 1, the next most critical factor with rank 2 and so on. The overall ranking was based on the total number of responses (including managers and site engineers).

Furthermore, a two-sample t-test was conducted among the means of responses of the two groups for each individual factor at significance level: $\alpha=0.05$ using SPSS to measure any significant differences among the respondents' perceptions.

The null hypothesis H_0 and alternate hypothesis H_1 considered in the analysis are given below:

H_0: There is no significant difference between the group means of two samples (i.e. $\mu_1 = \mu_2$).
H_1: There is a significant difference between the group means of two samples (i.e. $\mu_1 \neq \mu_2$).

If the p-value is less than 0.05, it means that the difference between the means of different groups is statistically significant and therefore, the null hypothesis is rejected.

After ranking all the factors on the basis of mean values, Spearman rank correlation was used to evaluate the strength of a relationship between two sets of data (Field, 2009). The nearer the value of R_s is to either +1 or -1 the stronger it is likely to be the mathematical correlation between the data sets and the more likely it is that the result is significant if there is, in fact, a relationship between the two variables correlated. The Spearman correlation rank coefficient test was performed to examine the hypothesis that there is no significant difference between the rankings of factors by the managers and site engineers. As suggested by Nolan (1994), the calculated values of Spearman's coefficient were compared with the critical value at 95% level. The Spearman's rank correlation coefficient was calculated using the following equation:

$$R_s = 1-6\sum d2n(n2-1) \qquad (2)$$

where n = number of pairs ranked and d = difference between corresponding ranks.

4. Analysis and Results

Using the RII values, the rank orders of different factors were obtained for all categories of responses: all responses, and separately for those of managers and site engineers. The results are presented in Table 1. The highest-ranking factors observed in all responses category have been discussed in more detail in the following sections.

Table 1: RII Values, Rankings, and t-Test Results of Various Factors Affecting Concreting Equipment Productivity

Factors	Overall		Manager		Site Engineer		t-test results at significance level 0.05	
	RII	Rank	RII	Rank	RII	Rank	F	p-value
Improper maintenance	0.915	1	0.954	1	0.879	2	10.083	0.002
Unskilled operator	0.868	2	0.887	3	0.851	6	9.560	0.003
Poor planning	0.866	3	0.944	2	0.795	14	241.639	0.000
Inefficient operator	0.861	4	0.846	5	0.874	3	7.736	0.007
Lack of coordination among different crews	0.856	5	0.841	6	0.870	4	8.662	0.004
Lack of materials	0.839	6	0.754	15	0.916	1	543.374	0.000

Wrong selection of equipment	0.834	7	0.836	7	0.833	9	1.120	0.293*
Location of batching plant	0.829	8	0.831	8	0.828	10	2.034	0.158*
Non-availability of spare parts	0.824	9	0.800	11	0.847	7	0.822	0.367*
Non-availability of work front	0.820	10	0.795	12	0.842	8	0.210	0.648*
Inexperienced equipment manager	0.815	11	0.821	9	0.809	13	12.028	0.001
Incompetent execution team	0.805	12	0.867	4	0.749	26	9.631	0.003
Bad relationship with the subcontractor	0.790	13	0.790	13	0.791	15	1.670	0.200*
Frequent downtime	0.785	14	0.810	10	0.763	12	13.818	0.000
Unskilled labour	0.780	15	0.733	16	0.823	13	14.162	0.000
Batching plant installation	0.776	16	0.779	14	0.772	18	0.003	0.955*
Discontinuity in operation	0.768	17	0.713	20	0.819	16	7.915	0.006
Wrong placing techniques	0.761	18	0.728	17	0.791	16	17.038	0.000
Incompetent supervisor	0.756	19	0.723	18	0.786	18	26.196	0.000
Bad weather	0.751	20	0.708	21	0.791	17	60.017	0.000
Location of pour	0.744	21	0.621	26	0.856	20	1.102	0.297*
Bad condition of hauling road	0.734	22	0.687	22	0.777	24	31.434	0.000
Traffic congestion	0.729	23	0.667	23	0.786	19	32.687	0.000
Ownership-Owned/Hired	0.720	24	0.646	25	0.786	20	20.375	0.000
Organization structure	0.695	25	0.718	19	0.674	29	0.612	0.436*
Logistic issues	0.690	26	0.610	27	0.763	24	7.019	0.010
Non-compliance of safety standards	0.685	27	0.656	24	0.712	27	7.750	0.007
Lack of training and motivation	0.680	28	0.600	28	0.753	25	1.717	0.194*
Lack of productivity awareness	0.629	29	0.554	29	0.698	28	0.298	0.586*

**The mean difference is significant at the 0.05 level.*

Improper maintenance was ranked as the most crucial factor affecting productivity of concreting equipment. Since concreting equipment are subjected to harsh working conditions, the slurry and aggregates tend to wear away piston rings and other components. However, in developing countries, equipment is usually engaged throughout various shifts and even on weekends and holidays due to tight project schedule and seven days a week operating conditions on many construction sites. As a result, the equipment maintenance team usually does not get sufficient time to carry out necessary maintenance tasks. Downtime resulting from machine breakdown during operations has a substantial impact on equipment productivity and organizational performance as a whole (Schaufelberger, 1999). In addition to this, the cost of doing the repair in an unplanned manner in the middle of a job is expensive (Kannan, 2011). Implementation of preventive maintenance has been highly recommended by the previous studies to reduce the overall maintenance cost (Makulsawatudom *et al.*, 2001; Alinaitwe *et al.*, 2007). Thomas and Sudhakumar (2013) also concluded that quick repair of faulty equipment is essential to avoid productivity losses.

Unskilled operator was identified as the second most important factor. With the advent of hydraulics and equipment technology, various equipment such as concrete pump, boom truck, and batching plant have evolved with precise control units. Therefore, skilled and well-trained operators are needed for their efficient operation and control. However, most of the construction firms in developing countries perceive training and development as a costly and unnecessary affair. As can be seen from Table 1, the lack of training has received a lower ranking by the respondents. Due to the rapid pace of development, shortage of skilled operator has become a major issue in many construction projects. The problem of skill shortage in the construction industry has been stressed by various researchers who uphold that management should help in skill development to achieve productivity enhancement (El-Gohary and Aziz, 2013; Jarkas, 2015). Allmon *et al.* (2000) argued that an increase in the construction real wages may resolve the issue of skill shortage.

The factor *lack of proper planning* was ranked third with RII = 0.868. Good planning is the backbone of any activity and concreting is no exception. Due to improper planning, concreting equipment is either under- or over-utilised. Alwi (2003) found that improper planning around equipment use incurs large overhead expenses. Non-availability of the work front also severely affects the productivity of concreting equipment. Since productivity of the concreting equipment depends on the continuity of the operation, frequent stoppages in operation due to factors such as unavailability of labour, resources, work front, as a result of poor planning lead to underutilization of equipment. Choudhry (2015) found that an open and spacious work environment also increases the productivity to a certain extent. Moreover, the negative impacts of adverse weather on concreting equipment productivity could be reduced with the help of careful planning based on weather forecast.

Inefficient operator was placed at the fourth position by the respondents. In many countries, the construction sites generally operate in a dual shift of duration of 12 hours each due to a tight schedule. It was found that on many sites, sufficient number of operators were not employed by the contractor in order to reduce the overall cost. Enshassi *et al.* (2007) found that working seven days per week without any off day among the top ten factors negatively affecting construction productivity. A proper design of a work/rest schedule is an effective means of improving a worker's comfort, health, and productivity (Yi and Chan, 2014). Working overtime also causes physical fatigue to operatives, decreases their agility, stamina and motor skills, leading to low productivity and de-motivation (Jarkas *et al.*, 2012). As a result, even a very competent operator can be demotivated due to various site related issues (Naskoudakis and Petroutsatou, 2016).

Lack of coordination among different crews was also perceived by the respondents as an important factor causing low concreting equipment productivity. In India, labour workforce comes from various parts of the country and therefore, cultural differences in terms of working style and language affect the level of co-ordination. Concreting is a cyclic process which includes several tasks such as batching, transportation, placement, compaction and return to the batching plant. Consequently, starting from the arrangement of the pipeline to fixing formwork and reinforcement, and finally placement and compaction of the concrete, all of these activities are interconnected, however, usually performed by different crews. Therefore, proper coordination is essential in order to ensure an efficient and uninterrupted operation of concreting equipment.

As can be seen from two sample t-test results presented in Table 1, out of 29 factors, statistically significant differences between mean values of 10 factors were observed while in the remaining 19 factors, no difference in mean values of different respondents group was found. For example, for the factors wrong selection of equipment, the p-value for engineer-manager is 0.293, showing a statistically significant difference in the mean values of the managers and site engineers. These differences are due to the difference in the perception of various categories of respondents on the relative importance of some of the factors. While factors such as equipment selection and location of batching plant that come under the purview of management were relatively high ranked by the managers, factors related to site job conditions such as non-availability of work front, non-availability of spare parts, and location of pour received higher preference by the site engineers. However, by looking at the high mean scores of each of the factor, it becomes evident that each of the stakeholders is in general agreement on the importance of each of these factors. Furthermore, the Spearman's rank correlation coefficient was calculated as 0.711 for manager-site engineers using equation (2). The values of R_s correlation coefficient was found to be greater than the critical value at the 95% level. Therefore, it can be concluded that the perceptions of managers and site engineers showed a strong positive correlation and there was ample agreement on the overall ranking of the factors between these two groups.

5. Conclusion and Recommendations

This paper's intention has been to make an empirical contribution and it is noteworthy that the findings add to the existing literature on productivity of concreting equipment, by looking at the specific issues causing low productivity. The findings of the study indicated that the main factors responsible for the low productivity of concreting equipment are related to equipment management and workers' skills. Moreover, the managers and site engineers were found to agree statistically on the relative importance ranking of factors affecting productivity of concreting equipment.

In developing countries, low focus on workforce training and skill development coupled with the rapid pace of development has caused an acute shortage of skilled workforce. In addition to this, organisations the low wages paid by the organisations negatively affects workers' efficiency and motivation. The answer to the skilled workforce shortage lies in providing better training opportunities and more attractive employment incentives. The incidents of equipment breakdown could be reduced by developing and following a proper maintenance schedule for the concreting equipment. The implementation of preventive maintenance has been highly recommended by the previous studies. Moreover, the availability of resources and work front through proper planning and coordination are crucial for the continuous operation of concrete equipment.

The factors identified through this research would help the site management in devising new methods to address these productivity issues. The potential implications of this study are relevant to the challenges facing both private and publicly funded construction projects regarding delays and cost overrun. It is the authors' hope that the insights provided by this study will be used by the contractors to improve the productivity of concreting equipment. Like many of the research works, this study also has few limitations. Further research is required to examine the impact of these factors on concreting equipment productivity in more detail. Moreover, two sample t-test results presented the statistically significant differences in the mean values of various factors. Future work may be undertaken to identify the exact causes of difference in the opinion of different groups of respondents.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Business Model Development for Modular Timber Building Systems

Joerg Koppelhuber
Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria
joerg.koppelhuber@tugraz.at

Johannes Wall
Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria
johannes.wall@tugraz.at

Detlef Heck
Institute of Construction Management and Economics, Graz University of Technology, Graz, Austria
detlef.heck@tugraz.at

Abstract

This contribution targets the current challenges in timber construction and the associated business structures of small and medium-sized enterprises in this sector. Initially, the situation of timber construction is presented based on recent developments in the Austrian corporate structures and their service portfolios as well as their future business activities. Subsequently, this paper deals especially with current challenges and the prevailing problem areas regarding current and future business models in timber construction and tries to show how promising business models as well as unconventional business concepts and trading ideas from non-construction industries can meet the prevailing market needs. These can be seen as incentives to rethink current business models focusing on long-term success within the timber construction industry.

Keywords

Business Model Development, Timber Building System, modularity, prototype, strategy

1. Introduction

The progressive development of the traditional carpentry industry towards an industrial production is dominated by advancements of material and jointing/connection technology. This development is also associated and supported with an increasing importance of sustainable construction, which means that ecological building materials are more demanded (Wall, Hofstadler, 2016). In Austria, this development is mainly determined by the timber housing sector. Almost one third of all detached and semi-detached houses are built in precast construction (as a so-called prefabricated house). Following an extensive research (Teischinger *et al.*, 2015) figures related to living space, increased between the years 1998 and 2013 by 7% for multi-storey timber buildings and by 33% for single-family homes built in timber. The total numbers of timber buildings, the share in residential construction in Austria has more than doubled within the past 24 years from 24% to 48% and has grown from 9% to 21%in terms of volume. The market share of prefabricated houses built in timber has already reached a level of 80%. Experts forecast high potentials in new sales markets such as industrial construction or multi-storey residential construction (Heck, Koppelhuber, 2015).

For all timber construction systems currently available on the market, prefabrication of individual components and elements, lead to a high prefabrication grade in general. All manufacturing processes, which are carried out under controlled conditions in a stationary production, show savings in the overall construction time (Kolb, 2007). The term industrialized timber construction generally refers to industrial production methods, such as series production in automated processes (Staib et al., 2008). The aim of applying industrial methods is to increase efficiency, reduce weather-related performance fluctuations due to a reduced production on the construction site (Girmscheid, 2010). In some cases this term is also understood as lean construction. These approaches are based on the production methods used by the Japanese car manufacturer Toyota, – often the automotive industry is used as a paradigm – and are used to optimize the process while avoiding a waste of resources. Lean management was developed as part of the car manufacturing industry in the first stage. Meanwhile the principles are also applied in the construction industry (Gehbauer, 2011).

The implementation of industrial methods and lean construction in the timber construction industry includes two major components: the planning processes and the production processes. In the planning stages, and especially in modular building systems, the repetition of component geometries in case of grid dimensions must be considered, as well as uniform and consistent material usage and clear material assignments (Heck, Koppelhuber, 2015).

The individual production processes implement factors of industrialization, such as mechanization and robotization, as well as standardization and rationalization (Girmscheid, 2010). Furthermore, the material and component logistics, the transport to the construction site as well as on site distribution are of major importance. With increasing modularity in timber construction also the degree of prefabrication rises constantly. This development is supported by the application of Building Information Modeling (BIM) and provides many possibilities. Some of them might be unconventional for the construction industry by implementing automated building processes. However compared to other industries with already widely used robotics in manufacturing, such as the automotive or electronic industry, the opportunities for an application in the construction industry, especially for industrial timber construction, are particularly promising.

2. Business models and approaches in companies

Numerous companies around the world are characterized by excellent products and services and, despite decades of economic success, they lose their competitive advantage almost for a sudden (e.g. AEG, Brockhaus, Kodak). These companies have failed to adapt their business models to changing market conditions, or due to bad strategic decisions. The ability to adapt to a dynamic environment is an industry-independent prerequisite for long-term enterprise competitiveness (Gassmann *et al.*, 2013). This adaptation is referred as business model innovation, which can be based on a new strategy or developed from a variation of already existing strategic considerations from other industries. Studies at the University of St. Gallen have shown, that around 90% of all business model innovations are ultimately recombinations of existing business models (Gassmann *et al.*, 2013).

Focusing on the construction industry, there is enormous potential for improving and adapting business models and their future application. Especially elements from the automotive industries are providing a solid foundation for future-proof business models. The following section presents several concepts.

2.1 Traditional concepts in the construction industry

The traditional, rather investment-cost-oriented business areas of the construction industry are the so-called general or main contractor (design-built) and the design-bid-built-concept of a total contractor (Girmscheid, 2010). Although investment cost-oriented service providers have a very different level of vertical integration and associated maturity levels with regard to planning and construction.

2.2 Progressive concepts in the construction industry

Novel or progressive business model approaches in the construction industry are the so-called construction-management-service-provider, the system-service-provider and the public-private-partnership-system-provider (PPP) (Girmscheid, 2010). These concepts can be summarized:

2.1.1 Construction-management-service-provider

The Construction Manager (CM) occupies a central position within the project organization for achieving the project's success. The CM services are usually provided by architects, planning offices and construction companies. Starting in early project development stages, the project is ultimately accompanied by a turnkey handover.

2.2.2 System-service-providers

The system service provider handles both, the planning and the construction processes as well as the operation of the finished object. This enables life-cycle-oriented solutions from a single source. The core competences of the entrepreneurs are extended by services such as financing, operation and maintenance.

2.2.3 PPP-system-providers

The basis of this concept is the partnership-based cooperation between the public sector (clients are municipalities, cities, etc.) and the private sector represented by construction companies in terms of so-called public-private partnerships (PPP). Therefore the focus lies on the joint implementation of construction projects on life-cycle-oriented solutions and enables the public sector to streamline administrative structures by reducing staff numbers and outsourcing to specialists.

2.3 Innovative approaches in non-construction areas

By combining different individual business model elements, new models can be developed. In addition foreign and unusual approaches can be used for the construction industry. Subsequently, three business model approaches are introduced, which can be applied to timber construction systems.

2.3.1 Complementary products or services

These approaches are mainly based on the so-called add-on or razor-and-blade strategy, for example by the expansion of the product strategy in terms of complementary products, which can be adapted to individual customer requirements. Crucial to the success of this business model approach is the realization of the so-called lock-in effect, which automatically bound the customer to purchase various complementary products after purchasing the basic product. This type of approach has not yet reached the concepts of construction management, but it is indispensable in daily life for numerous business models.

2.3.1 Differentiation strategy

This business model approach is mainly based on the availability of a total package, which clearly stands out from the packages on the market. An exclusive differentiation by the price is not given. Therefore this approach is usually associated with the development of a completely new product and often more associated with marketing than a business model.

2.3.2 Individualized mass production

This approach is mainly based on the approaches of the so-called mass costumization, which can also be explained with individuality off the peg. In this case, the individual requirements are met by compatible individual components and a modular product architecture. The strategy exploits the cost and time advantages of mass production are used extensively, in combination with individual customer-oriented product design.

3. Suitability assessment of business models

Under the guiding principle of adaptability, existing business models from literature and practice must be investigated before the actual suitability assessment of business model innovations. In this first step during the generation of ideas, partly seemingly inappropriate models are also taken into account. In order to launch a transparent and conclusive aptitude test, a systematic approach is developed by a catalog of criteria especially developed for use in timber construction (Heck *et al.*, 2016). This enables a mandatory pre-filtering of the researched business models, which are subsequently bundled and subjected to an initial analysis.

3.1 Structuring and categorization

The criteria development for a constitutive assessment of business model ideas regarding to their fundamental suitability initially includes both a structuring and a categorization level. Therefore the business models were bundled, taking into account the industry affiliation and their relevance for the task. In addition to the detailed categorization, the structuring level includes a brief description and selection of all common applications of the individual business model approaches. Additionally, the current use in the industry can also be assessed (Heck *et al.*, 2016). This assumption is not an evaluation criterion and therefore merely an indication of innovation required. Subsequently, an individual evaluation of the different models take place on the basis of previously defined criteria.

3.2 Overview and suitability assessment

For the further investigation of the suitability in the timber construction industry the definition of criteria is necessary, which makes it possible to adopt a subdivision of the relevant business models. The previously collected business model ideas are evaluated using a three-step process.

3.2.1 Level 1 – General suitability

In this first level, it is determined to what extent the respective business model approaches are suitable for the industry in general and specifically for the company itself. The first evaluation criteria are therefore the sector suitability and the company appropriateness.

3.2.2 Level 2 – Dimensional suitability

The second level defines which dimensions (e.g., customers, partner, products, etc.) of the particular business model idea are relevant. This is especially necessary for non-industry business models, as these have significant relevance only to certain dimensions. The evaluation criteria are consequently dependent on the dimensions used for the business model description.

3.2.3 Level 3 – Market suitability

In this third level it is stated for which markets the respective model is suitable. The evaluation criteria distinguish between the public market, the institutionalized market and the private market. A further subdivision, for example in single-family house construction and multi-storey residential buildings, can also make sense depending on the situation.

If a business model idea is classified as inappropriate or irrelevant in one level, it is eliminated for further processing. The result of the criteria catalog is a certain number of relevant business model approaches for further processing. While no upper limit of the number of business models can be determined in the idea extraction, the total number of the relevant business model ideas should not exceed a total number of 25 after the treatment in the criteria catalog. This is necessary since the time required for the further work stands in no relation to the ultimate benefit.

3.3 Analysis of business model approaches

For a clearer processing, the business models identified as relevant are grouped according to the previously defined criteria. Thematically similar business models are summarized and subsequently subject to an initial analysis. Since neither an exclusive consideration of the company itself nor a singular investigation of the company environment is expedient at this early stage, a so-called SWOT-analysis proposes a combined analysis method. The term SWOT stands for the acronym Strenghts, Weaknesses, Opportunities and Threats. The first two factors describe the company's internal conditions and the latter two the external environmental conditions of the business area. The SWOT-analysis integrates these two perspectives and thus form an integral part of the strategic situation analysis and general strategy determination (Simon, von der Gathen, 2010). By analyzing individual business model approaches, the preliminary suitability assessment of the criteria catalog can be checked. The vision development represents the completion of the aptitude assessment and should result in a maximum of ten relevant business approaches, which form the basis for further processing.

4. Derivation of business model approaches for modular timber construction systems

Following a basic analysis and a suitability assessment, the actual business model development takes place. Therefore the relevant business models are adapted with the results of the SWOT-analysis, in order to ensure a structured, goal-oriented and comprehensible creation process, in two stages. First, a generic business model prototype is created. In this preliminary business model, the ideas and concepts for a defined business area is adapted to the needs of the sector and/or the company. Individual company characteristics should only be taken into account as far as necessary in this stage, since too much concretization without sufficient analysis can lead to grave misjudgments. If elements are missing like necessary resources, personnel etc. the business model prototype can serve as a basis for further model developments.

4.1 Exemplary business model prototype

A business model prototype, like the final business model, is described by dimensions and represented in a business model matrix. The goal is to meaningfully combine the information gained from the respective SWOT-analysis in a business model matrix. The following prototype is based on an elaboration of the two phases of development described above and was established in a research project at the Institute for Construction Management and Economics at Graz University of Technology for a medium size Austrian timber construction company. The contents of a prototype are based on twelve analyzed business model approaches and several expert workshops (Heck *et al.*, 2016).

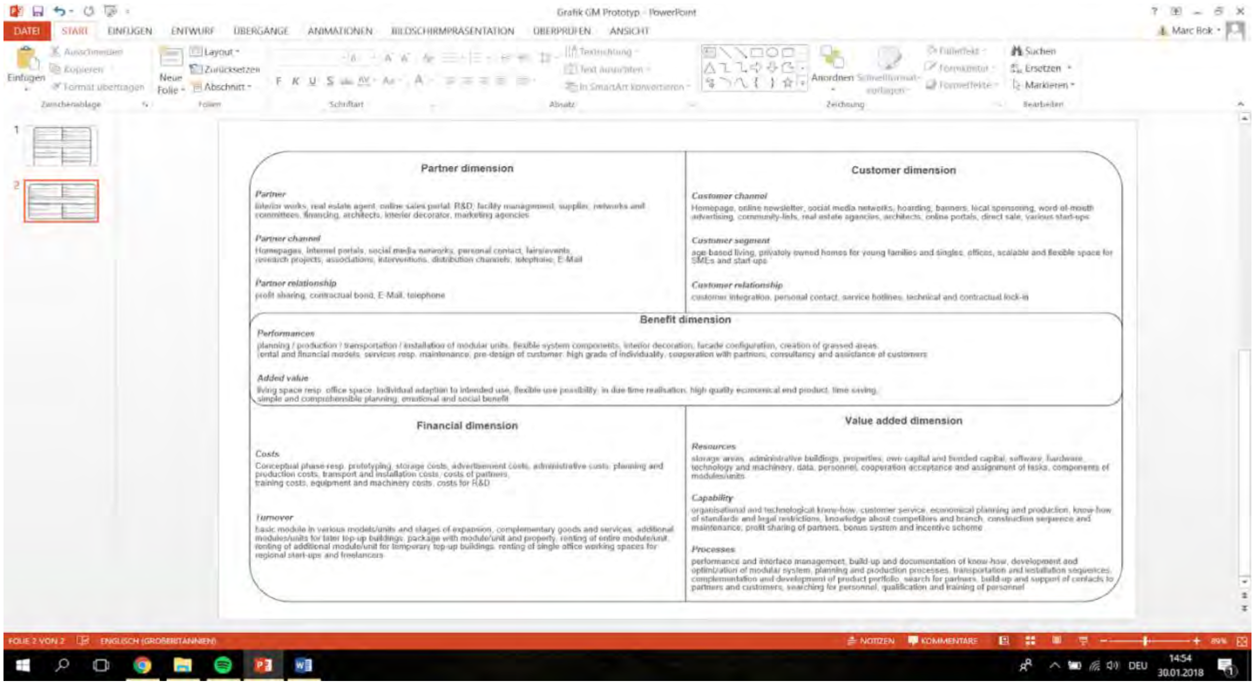

Figure 1: business model prototype for modular timber construction company in accordance to research project TU Graz (Heck *et al.*, 2016)

The dimension and element classification and presentation of the procedure is based on the methodology of D. Schallmo (Schallmo, 2013).

4.2 Concretization and analysis of the prototype

Increasing concretization of the respective dimensions and different analysis procedures, a final business model emerges. The concretization process takes place through the application of business-economic instruments. First of all, an analysis of the respective corporate environment must be used to check whether the assumptions made previously also correspond to the company's practice. This requires detailed studies and comprehensive analyses. Possible analysis methods for this step are the so-called PESTEL-analysis or macro environment analysis (Hungenberg, 2014) and the industry structure analysis (Porter, 1980). Subsequently, a detailed analysis of company-specific characteristics or influencing factors is carried out, in order to estimate the scope of action for these internal corporate values, procedures can be applied, starting with the ABC-analysis (Schawel, Billing, 2014) to the customer satisfaction survey. The use of analysis methods in the concretization phase depends very much on the situation of each company. Using additional analysis methods in the business model development, a more realistic result can be generated. Regardless of the chosen analysis methodology, the collection of critical success factors, the elaboration of the causal link and the creation of scenarios are imperative for the further specification of a business model prototype. The critical success factors are acting as few variables that influence the long-term success of a business model. It is important to identify the interactions of these factors and illustrate them using a crosslinking-matrix. By creating various scenarios, an attempt is made to consider future developments at an early stage in the business model creation.

4.3 Creation steps and synergy potentials

The processing order of dimensions (e.g., customers, etc.) is clearly defined for both business model creation and previous prototype development. Starting with the so-called customer dimension, which is particularly relevant for the further provision of services, the so-called benefit and value creation dimensions are focused. These two dimensions targeting the question of what is offered to the previously defined customer and how this product or service is created. Subsequently, the determination of the relevant partners (e.g. suppliers and subcontractors, etc.) takes place. This is done by editing the so-called partner dimension. The last dimension to be worked on is the so-called financial dimension, in which the individual costs and revenues must be listed as precisely as possible. By adhering to the processing sequence by means of a control loop, a profitable development of the individual dimensions is ensured.

5. Conclusion and Outlook

The aim of the present contribution is to raise awareness of the current challenges of timber construction and the related business structures of small and medium-sized enterprises in this sector. In connection with the predominant corporate structures in Austria and the associated service portfolios of the timber construction industry, the areas of action were outlined, especially with regard to future business activities. Based on the results of a research project the four dimensions, the customer dimension, the user dimension, the added value dimension and the partner dimensions, as well as the financial dimensions within a company have been considered in detail. Subsequently, these dimensions were examined with regard to their specifications in timber construction. This has been an iterative process, resulting in a continuous rise of maturity levels of the target goals, supported by a SWOT-analysis for the specific applications within the modular timber construction industry. Finally, it should be noted that the criteria presented in this study, based on a larger research project within a Small and Medium Entrepreneurs (SME) of the timber industry, are single approaches to possible business models. For an overall application, these approaches are not described sufficiently enough. However, it is important to decide for each specific situation and vision of the company and to clarify the boundary conditions for a business model development on the basis of the respective circumstances. Therefore the representatives of the company are required to develop an honest approach to define goals based on the specific situation, brought in by the individual knowledge from the enterprise.

5.1 Flowchart of a possible business model creation

Fig. 2 shows the procedure of a business model generation. It is important to follow the steps in the illustrated order to prevent wrong estimations and considerations of boundary conditions.

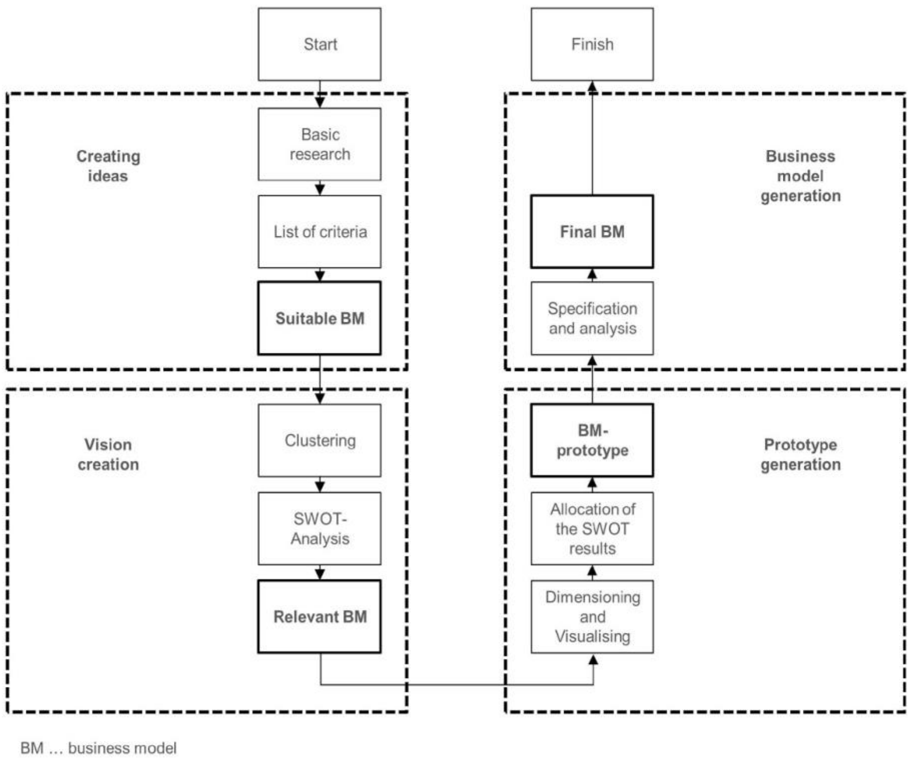

Figure 2: flowchart of a business model development in accordance to research project TU Graz (Heck *et al.*, 2016)

At the beginning, major issues focus on the customer dimension and how their requirements are satisfied through the whole process, based on specific clients. Therefore a specification of necessary services for user and value generation is essential. Additionally to financial and technological aspects human resources also have to be considered, to improve the interactions between the customer and the project requirements. The specification of these services results in splitting up support and management processes. Another important aspect is the need for partners, and supporting relationships, who contribute to the value creation in terms of providing resources and capabilities, needed for the implementation of value added processes. In addition it is important to know how these activities must be divided and allocated taking care of the individual strength. The financial dimension considers the cost structures, required to show the cost mechanisms for the next planning stages. The interactions of the declared dimensions illustrate the dependences between the individual dimensions. Therefore it is necessary to start with an assessment of the existing competences and objectives especially focusing on the timber related departments of the company, in order to identify the current value and share of timber related activities, to examine their future applicability in accordance with the specified customer and market requirements.

5.2 Unconventional ideas for the future

Innovative approaches, which are delivered through business model development not only create alternative sales opportunities, but also lead to the identification of unique selling propositions (USP) in combination with the application of the best bidder principle. Rethinking the existing business model in timber construction, as described in this article, active risk management leads to maintain an agile organization. Due to the progressive improvements in timber construction and the application of new fabrication techniques common business models need to be reconsidered contributing towards a more efficient and sustainable timber construction industry.

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Building Information Modelling Adoption for better cost estimation: Sri Lankan perspective

Anushka Rathnayake, Sajedeh Mollasalehi, Ahmed Aboumoemen
University of Salford, Manchester, UK
A.P.Rathnayake@edu.salford.ac.uk, S.mollasalehi1@edu.salford.ac.uk, A.a.aboumoemen@edu.salford.ac.uk

Udayangani Kulatunga
The University of Moratuwa, Colombo, Sri-Lanka
U.kulatunga@salford.ac.uk

Hamed Hyab Samir
Basra university, Basra, Iraq
Hamidtemeemi@yahoo.com

Abstract
To achieve competitive productivity and performance over the past eras, the growths of innovative technological concepts are promptly increasing. The waves of Building Information Modelling (BIM) have made everyone's in the construction industry gushing about BIM in building and construction expos. BIM has potential to influence everyone's professions in different ways within the construction industry. Most importantly BIM is capable of improving the accuracy of cost estimates through various BIM related tools which can be applied in the different stages of the traditional cost estimation process. Most of the countries both developed and developing have already re-aligned their cost estimation process with BIM and experiencing the benefits of it. Although the concept of BIM is slightly practiced in Sri Lankan construction industry yet, the majority of organizations still haven't adopted BIM. Therefore, this paper aim is to investigate the level of BIM adaptation of Sri Lankan quantity surveying organizations for a better cost estimation process. The study is interesting because the new knowledge will help to develop strategies for professional development and update the education curricula to train the Quantity Surveyors to face future challenges. As a visual database of building components, BIM can provide accurate and automated quantification, and assist in significantly reducing variability in cost estimates.

Keywords
BIM, Cost estimates, Adoption, Sri Lanka, Quantity surveyor.

1. Introduction
For any construction project cost estimation is an essential task for budgeting and bid preparation and cost planning (Sheikh, 2013). Cost estimation is, predicting the most realistic figure ensuring that sufficient construction funds are available at different or any given stage of a project (Avsatthi, 2016). Therefore, Construction cost estimating involves collecting, analyzing, and summarizing all available data for a project (Holm et al., 2005). Different types of estimates are available such as preliminary estimates which becomes the fundamental guideline to determine projects' feasibility and elemental cost estimates which calculate the total estimated cost of construction project considering the major elements of a building.

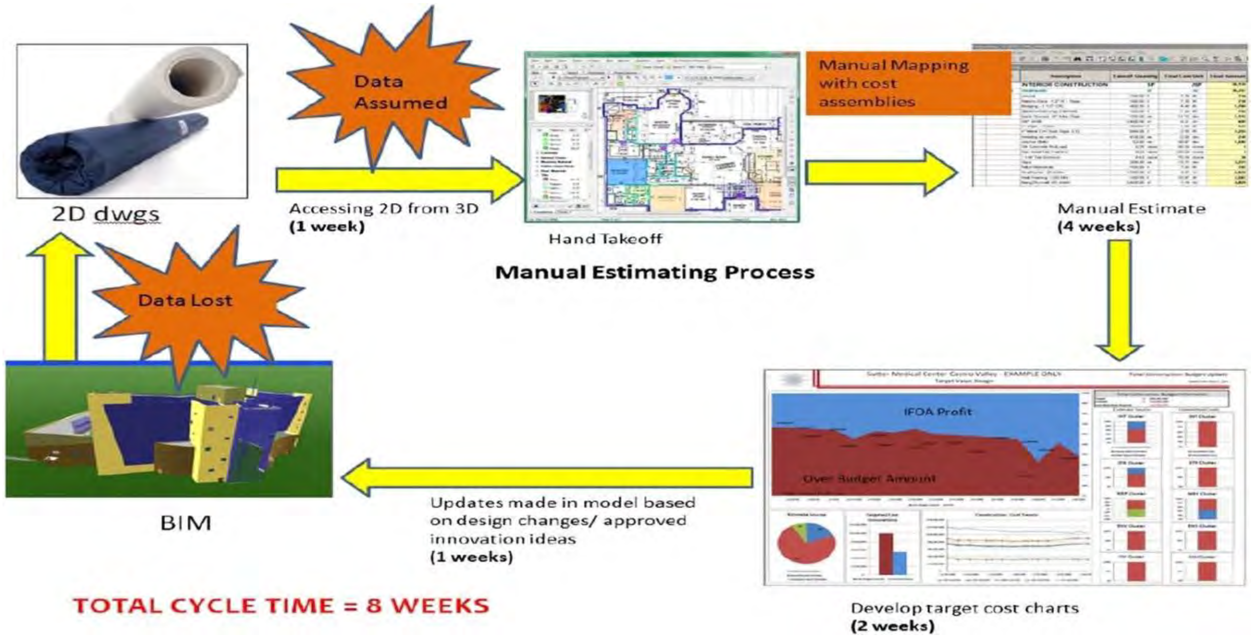
Highly accurate estimates reduce the changes of uncertainties and risks (Avsatthi, 2016). Perhaps, most importantly, an accurate estimation keeps all parties focused on delivering a project on time and under budget. It holds a developer and construction company accountable for increased costs and overruns. When planning a project, such as building, costs can overrun seriously if correct estimates are not considered (Michael, 2017). Therefore, as one of the defining features of successful progress, accurate project cost estimation must take a front seat when it comes to setting up a project's parameters. It's impossible to underestimate the importance of cost estimation when it comes to successfully completing a project. Before even approaching a project, it's important to get a handle on cost estimation to help keep you on task and in touch with project constraints and limitations.

Sri Lanka is going through a major urbanization and economic development with the end of civil war 2009. As a developing country (IMF, 2012), construction industry plays a major role in development and achievement of the goals of the society (OBG, 2016). The Construction is one of the largest industries in Sri Lanka and contributes to about 8% of the Gross Domestic Product (GDP) (Trading economics, 2016). The Construction industry has complexity in its nature because it contains a large number of parties as clients, contractors, consultants, stakeholders, shareholders, and regulators. According to Central Bank (2015), out of the total workforce of 6.2 million people, therefore, the construction industry is a measurement tool for Sri Lanka, which indicate the economic situation (Langford *et al.*, 2000).

The demand for the Quantity Surveying profession is growing day by day in Sri Lanka (Withanagamge and Senevirathne, 2016). Cost estimation is the most performing role among Sri Lankan quantity surveyors. The success or failure of a project relies on the accuracy of several estimates done throughout the course of the project (Navon, 2005). Hence, the traditional practice of Sri Lankan quantity surveyors hinders the accuracy of cost estimates (De Silva *et al.*, 2014; Gunasekara & Jayasena, 2013; Perera *et al.*, 2010; Weddikkara 2013). Therefore, traditional cost estimation practice is one of the major challenges within the Sri Lankan quantity surveying organizations.

2. Traditional cost estimation process

Accurate cost estimates are essential for a transparent construction process and for the development of the Sri Lankan construction industry (Fernando, 2015). However, preparation of accurate cost estimates is crucial due to the traditional practice of Sri Lankan quantity surveyors (Dissanayake, 2015). Traditional practices can be defined as a particular ethnic group, that has been practicing the same culture since ancient time (Wikipedia, 2017). Also, a continuing pattern of culture belief or practices (Dictionary.com, 2017). Hence, according to researcher's point of view, the traditional practice can be defined as a particular ethnic group continuing a specific pattern without adopting to modern technologies.



As illustrated in figure 1, traditional cost estimate process starts with series of 2D CAD drawings provided by the design team. 2D-based drawings or documents, whether they are designed by hand or with the help of CAD tools, are also error-prone. 2D documents are designed based on other 2D documents developed by a manual process; wrong inputs and interpretations are therefore very common since it is very hard to process complex situations, in particular, connections between various building elements (e.g. a cross-section of the connection of a beam, a column, a wall and a slab) in a 2D frame. Therefore, it does not cater for the accuracy of the estimate using the available set of drawings and specifications (Rathnaweera, 2015). Moreover, as illustrated in above figure it takes up to one week of time to make it 3D using various assumptions.

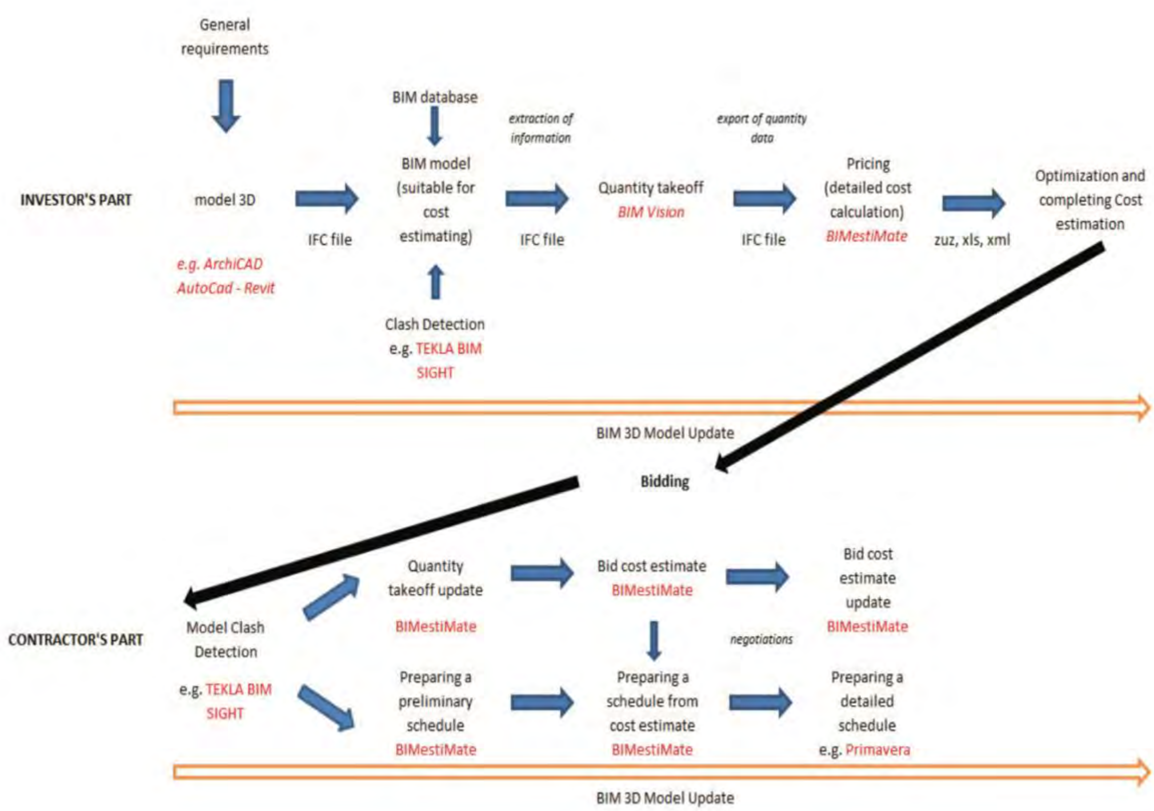
Based on these drawings QS's doing taking off quantities of tallying components from printed drawing sets which is a very time intensive process which takes up to 50-80% of the time needed to create a cost estimate is spent just on quantification (Wong *et al.*, 2014). Extracted quantities from drawings export from spreadsheets to costing applications to produce the project cost estimate. This might take up to four weeks of time to produce cost estimates with manual mapping with cost assemblies. Finally, updates should be carried out considering the design changes. So, the entire process of preparing cost estimates takes up to eight weeks of time to get complete. According to a recent survey carried out by Dissanayake *et al.* (2015), one of the QS had mentioned: *"If we have a reasonable time to prepare estimates with the use of designs developed by Architecture and Engineering departments of the organization it will result in better estimates"*.

Moreover, in Sri Lanka cost estimates are prepared mainly based on historical cost data. Yet, the performance of usage of historical cost data in cost forecasting in Sri Lankan consultancy practice is poor (Jayasinghe *et al.*, 2015). Poor documentation of past records and lack of availability of cost data are the main causes for poor consultancy practice of QS (Illankoon, 2013). Therefore, most of the cases limited and less accurate information is available by the time of preparing cost estimates, may mean the quantity surveyor must make assumptions about the design details of a project (Perera, 2013). According to one of the respondents *"We do predictions up to the maximum level, on the basis of whatever the information we have"* (Diassanayake *et al.*, 2015). If the provided information is not accurate, then the entire cost estimate is at a risk due to wrong assumptions made by the QS. Therefore, the majority of the Sri Lankan quantity surveyors are not satisfied with the accuracy level of existing estimating practices (Britto, 2013).

3. BIM-based cost estimation

Most of the developed countries which faced the same problems have successfully improved the accuracy of cost estimates by adopting BIM, into their estimation process. BIM has changed the way of buildings are designed, documented, analyzed, procured, constructed and managed by introducing a new culture of working for all construction disciplines, (Aranda-Mena *et al.*, 2008; Hardin, 2009). Most importantly it improves the accuracy of cost estimates by removing unwanted time-consuming tasks from entire estimation process.

According to figure 2, the foremost step in BIM-based cost estimation is to prepare a 3D model of a building along with a knowledge base, that is, all the vital information available at each stage of the investment. Tekla BIM Sight allows detecting clashes from the intersection of elements in superimposed drawings. Therefore, corrections can be done at the early stage of the project as it collects information about the building structure using a facility BIM model, projections, sections, and guidelines, as well as cost estimations.



The second step is transferring quantities directly from the model (IFC file) or is extra-added if it is necessary for cost estimation. This approach associates with software such as, Autodesk QTO, Vico Office, and CostX which are specialized in Quantity Take-Off (QTO) and enable to transfer the BIM models and their embedded information from BIM design tools into their system. These tools could be used for both automated extraction and manual take-off features. Such calculations are more accurate with fewer errors and omissions. They can generate visual take off diagrams while providing visualization of models whereby the quantity surveyor can mark off the building components using colors enabling to cross-check the take-off lists and to see which components have or have not been included in the estimate (Eastman *et al*., 2011). During the construction process, it allows quantity surveyors to insert additional clarifications to the model to clarify the conditions wherever necessary for the inter-linked items and assemblies. Even if the Quantity surveyors are not having an in-depth understanding of BIM design platforms, this approach provides an advantage for the quantity surveyors to work using familiar QTO software.

Once the quantity take-off is completed and both descriptions of the identified items (introduced in the design process from a library or adopted individually) and their quantities are prepared, the actual cost estimation may begin. As the unit rates are computed for all items, the items are priced automatically. Costs of all items are calculated automatically "on the fly" on the basis of adopted or computed prices. A list of the elements that are estimated is created automatically as records in the cost estimation application, which makes it ready for valuation.

4. Methodology

As BIM is currently becoming the buzz word among the construction industry, an assumption was made prior to the research investigations that a few organizations are taking BIM as potential business marketing, which led to the claims of implementing BIM, although their statuses were arguable. Many publications recognize as the primary technology for BIM the use of 3D parametric tools (Construction Project Information, 2009; Eastman *et al.*, 2011; Elvin, 2007; NIBS, 2007; Smith &Tardif, 2009). Therefore, organizations were selected based on the use of BIM tools such as Revit, Costx.
To identify the company which at least, has started implementing BIM / engaged in a BIM-based process, a few techniques were engaged:

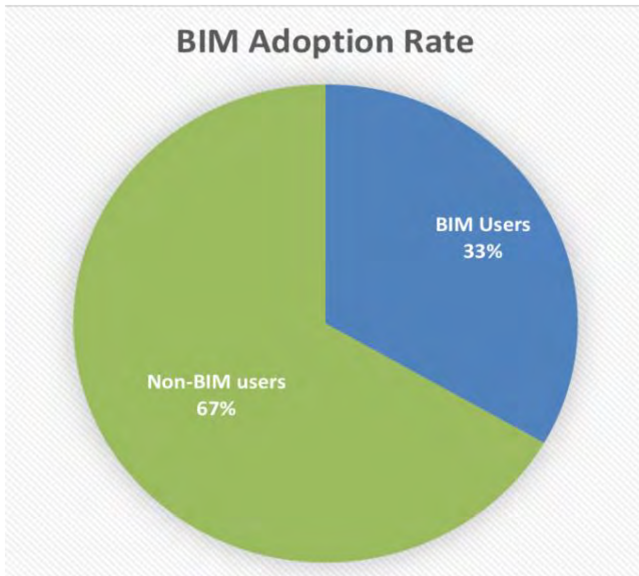
a. Direct communication with QS organizations in Sri Lanka
b. Attachment and collaboration with ICTAD and IQSSL (Institute of quantity surveyor's Sri Lanka)
c. Direct communication with Construction professionals in Sri Lanka

Nine companies were identified through above techniques, contact numbers and email addresses were obtained. Applications for conducting preliminary interviews were then requested via phone calling and emails. Out of Nine companies, 5 positively responded to the request. A preliminary interview is a process where the researcher attempts to get a brief picture regarding the current involvement of BIM within the company.

Following questions were asked during the preliminary interviews, which are:
a. As part of screening process: To make sure the company has fully/partially incorporated BIM into their business.
b. As part of refining the interview question: To get a brief picture of the company. This information helps to identify related questions that suit the company level of BIM usage.
c. As part of research strategy: To develop trust and credibility so that the researcher could gain access to carry out data collection.

5. Discussion

According to figure 3, out of nine organizations, there were only 3 quantity surveying organizations which are 33% currently using BIM or engaged with a BIM process. Rest of the organizations (67%) are not using or in a process of adopting of BIM.



Organization A is the first Sri Lankan Organization who started using BIM four years ago. The organization has acquired few licenses for Revit Structure, Revit architecture, Costx-5D estimating, MS Project and AutoCAD. Most importantly, they are the first Sri Lankan organization who's dealing with the First Sri Lankan BIM project going on in Havelock town, Colombo. Other two organizations also using above-mentioned BIM related tools, apart from that one organization using CATO as well. Moreover, they do operate in international markets such as Oman, Quarter, United Arab Emirates.

These organizations offer following services in terms of BIM,

A) Author the 3D model (Revit)
B) Extract drawings from the 3D model
C) Determine associated information such as the Material Taking Off, Weight, Surface Area and Centre of Gravity (Costx)
D) Prepare cost estimates using Costx
E) Conduct Automated Clash Check
F) Deliver Walkthrough Review

Moreover, more than 88% of quantity surveyors agreed that BIM enabled cost estimation process in more effective than the traditional cost estimation process. As BIM tools capable of improving rich three-dimensional (3D) context by aiding QS to identify significant cost-sensitive design features (by overcoming significant limitations of 2D drawings. 3D models created by using BIM technology is capable of providing more transparency on the design for the quantity surveyors. Moreover, BIM has further helped estimators to visualize real-world conditions through a virtual 3D construction, which is a particular benefit in complex designs that are not easily represented in floor plans. Therefore, visualization is one of the basic application of BIM through 3D models, which gives a clear picture of the project scope and characteristics, for quantity surveyors to take accurate measurements from the drawings. Therefore, it has eliminated time-consuming tasks such as double counting, re-measurements, and missing elements. Therefore, quantity surveyors have more time to consider other aspects of the estimate rather counting on elements.

Moreover, many quantity surveyors mentioned that it is very beneficial for them where the QS can carry out a 3D virtual walk-through and make sure everything in the model is factored in the QTO. Any changes made to the model such as editing of plans, sections, elevations or 3D view within the model automatically made to all other documentation, drawings, and outputs, by saving time for the manual revisions. Consequently, design errors caused by inconsistent 2D drawings are eliminated. From the QS perspective, if clashes can be addressed in the design stage, there is a better chance a variation will not occur on site. Also, BIM allows them to identify these conflicts from the federated model before they materialize in the field and this can exclude costly variations during construction. Due to earlier clash detection, it has increased the cost efficiency of the project and reduces the risk of running behind schedule. Moreover, it has reduced errors and omissions in the design drawings by helping quantity surveyors to make correct assumptions and decisions to prepare accurate cost estimates.

Apart from that, due to the rich nature of data within BIM objects, QSs allowed to extract and distinguish information from the 3D model beyond traditional measurements, such as the number of columns within a particular material characteristic. Quantity surveyors can upload or download any information at any stage of the project from these models. Moreover, information can be easily picked from the model to perform an order of magnitude and elemental estimates, even if the geometry from BIM at early stages of design comprises in few quantities. Most importantly the most useful tasks that can be automated through BIM use is quantity takeoff (QTO). A BIM-based model is an assembly of objects defined by specific properties, some of which are the element's geometric attributes. Most BIM tools contain routines to perform calculations using the element's geometric properties and provide spatial quantities like area and volume in text form. BIM-based QTO is reported to provide simpler and yet more detailed and accurate cost estimates of the project, reducing time and expenses.

6. Conclusion

The accuracy of cost estimates is essential to the overall success of the construction project. However, the traditional practice of Sri Lankan quantity surveyors hinders the accuracy of the cost estimates due to challenges such as 2D drawings, manual quantity take-off, lack of information, poor visualization, etc. As a new technology, BIM assist in cost estimating will not obsolete estimators; rather, it promises to free them to focus on higher value task than counting, returning increased value to project processes. It improves the accuracy of cost estimate process through automate quantity take-off, 3D models, improving the information flow, improving visualization etc. as discussed in the literature. Hence, BIM adoption rate for the Sri Lankan construction industry still in infant level, as only a few organizations using BIM tools but the majority of them are not. With the current demand for construction projects in Sri Lanka, BIM is likely to become the project delivery standard in near future. Therefore, it is high time for the Sri Lankan construction industry stakeholders to re-align their organizations with BIM in order to gain more benefits for the overall project life- cycle by increasing total productivity.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

Investigating Innovative Culture Level and its Influence on Labour Turnover in Organisations

Naseema Ebrahim[1], Innocent Musonda[2], Chioma Okoro[3]
[1,2,&3]School of Civil Engineering and Built Environment, Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment
University of Johannesburg
imusonda@uj.ac.za; chiomasokoro@gmail.com

Abstract
Innovation is ingrained in the process of building dynamic and creative capabilities in an organization. However, if employees are not encouraged to develop capabilities and positive attitude at work, a strong innovation culture may be impossible to realize. Poor innovation culture could in turn affect labour turnover and productivity. The objective of the current paper to identify the innovation culture levels in organisations and its influence on employee retention or turnover. Pilot interviews with senior management and a main field questionnaire survey were used to collect data from conveniently sampled organisations including FCMG, service, manufacturing and construction organisations in the Gauteng province of South Africa. Empirical data were analysed using the Statistical Package for Social Sciences (SPSS) to output descriptive statistics. Findings showed that across all the industries, innovation was generally high, with employees being an important source of information and encouraged to ask questions when trying to perform certain tasks. The findings of this study could assist management in organizations, including the construction industry, to identify that could encourage innovation in their respective establishments and thus guard against labour turnover.

Keywords
Construction industry, innovation, labour turnover, employee retention, manufacturing industry, South Africa

1. Introduction

High labour turnover and job dissatisfaction pose a recurrent challenge to organisations globally and there is virtually no organisation that is immune it, regardless of the size, technological advancement, market focus or economic sector (Hana, 2013; Akinyomi, 2016; Harden et al., 2016; Park et al., 2016). Organisations faced with unhappy employees and high labour turnover lose skilled and qualified employees, and run into many financial and non-financial problems including poor organisational performance, low employee morale, increased costs (for recruiting, training and development of new employees, cost of inefficiency of new employees), delays on tasks, poor quality of service and lower productivity (Thomas, 2013; Ayegba and Agbo, 2014). Five out of ten businesses do not survive past the first five years in operation, with the majority not even making it past the first year and this is partly as a result of high labour turnover, job, career and pay satisfaction, unionization and so on (Thomas, 2013). Many strategies have thus been espoused to address the problem of labour turnover and these include supervisor support, improving learning and working climate and conditions, employee rewards and incentives, as well as improved remuneration packages (Govaerts et al., 2010; Terera and Ngirande, 2014;

Akinyomi, 2016). However, few studies have focused on the role of innovative culture in the retention of employee in an organisation. Innovation in an organisation is a critical driver of competitive advantage, success and economic performance (Hana, 2013). An innovative culture in organisations contributes to increasing their potential, competitive advantage, a higher efficiency of processes and a higher profit.

Extant literature investigated the relationship between innovation and size and type of organisation or sector and innovation as well as the role of knowledge in innovative culture enhancement (Hana, 2013). Habib et al. (2014) explored the impact of organisational culture on job satisfaction, employee commitment and turnover intention, but did not really include innovativeness. Furthermore, the relationship amongst innovation, training and turnover was focused on in Kesen (2016) and between turnover intention and actual turnover in Sun and Wang (2016). In addition, Kundu and Gahlawat (2016) investigated the relationship between human resource (employee retention) practices on an organisation's performance. However, few studies have investigated the relationship between innovation and retention, especially in South Africa. The current study posits that an innovative culture leads to employee retention in an organisation. The objective of the current study is therefore to establish a relationship between an organisation's innovation culture and employee retention. Findings from the study will assist employers in developing strategies to manage and maintain a productive workforce.

2. Literature Review

2.1 Labour turnover

Turnover is generally defined as the movement of an employee out of an organisation (Sun and Wang, 2016). It is the rate at which an organisation loses its employees. It is the rate at which an organisation replaces its workforce (Akinyomi, 2016). It is necessary to note that an affliction such as high labour turnover does not go unnoticed in an organisation. A desirable degree of turnover is acceptable as it creates incentives and helps maintain creativity (Kesen, 2016). Nevertheless, excessive turnover is detrimental to organizational performance because it can disrupt service delivery and create additional costs for the organizations in replacing the leavers (Sun and Wang, 2016).

Labour turnover is influenced by human resource management related issues. The role of management in maintaining and managing human resources in an organisation contributes to labour turnover. These roles are associated with including compensation, job security, motivation, leadership, training and development as well as support and innovation culture (Irshaad, 2012; Sun and Wang, 2016). This suggests that one of the ways through which an organization can reduce turnover is through innovation. This suggests that organisations which tend to support creativity, as well as free and productive environments will have a lower percentage of employee turnover. In other words, an organisation's culture and strategic alignment to innovation has an impact on employee retention or turnover.

2.2 Organisation culture

Organisational culture is a set of different value systems, beliefs, attitude, behaviour, norms, rules and regulations that reveals how the organisation functions (Habib et al., 2014). Each organisation has a specific culture which can be determined by a number of factors. Culture can be defined as the underlying values, beliefs and codes of practice which define and make a community what it is (Dalkir, 2005). However, culture could either be innovative or destructive, depending on the way an organisation functions.

2.3 Innovative culture

Innovation was first conceptualised by Schumpeter in 1934, with theories centered around entrepreneurial innovations (Śledzik, 2013). However, his views have changed over time to include a wide range of spheres and approaches including social, organisational, institutional and political perspectives (Śledzik, 2013; Park et al., 2016). Innovation is basically the introduction or adding of new things or methods to existing ones

(Okpara, 2007). It is the ability to make or otherwise bring into existence something new (for instance, a solution, method, device, art or idea) or an implantation of creative inspiration (Okpara, 2007). It could be a launch of a new product or species of already known product, application of new methods of production or sales, opening of a new market, acquiring new supply sources and new industry structure such as creation or destruction of a monopoly position (Śledzik, 2013).

Innovation within an organisation is crucial. Organisations seeking profits must innovate in order to be competitive and dynamic (Śledzik, 2013). Most organisations cannot stay afloat without improving the ability to innovate in order to remain competitive, as was the case with Kodak, which were complacent in innovating new photographic and imaging products and could not keep up with the technological challenge of global competition (Forbes, 2012).

In order to successfully create an environment of innovativeness in an organisation, certain traits must be inherent or exhibited by the organisation, which in turn becomes a way of doing things in the long run, described as culture culture (Rao and Weintraub, 2013). These traits include the following:

- Values – These are in line with that of an innovative culture. Innovative organisations create an environment conducive to learning and creativity and are typically entrepreneurial organisations
- Behaviours - Certain behaviours are necessary for maintaining an innovative organisation. Management needs to inspire employees to carry out challenging tasks; employees need to be engaged regularly and provided with the necessary support and coaching to adapt to change where necessary.
- Climate - An innovative climate (or environment) cultivates engagement and enthusiasm. It also challenges employees to take risks within a safe environment, thus fostering learning and encouraging independent thinking.
- Resources - It is necessary to have the correct resources, such as human, finances and time, in order to innovate. Without sufficient resources, it becomes difficult to be innovative because tasks have to be carried out with less than the employees require.
- Processes - In order to function efficiently, the organisation must have adequate processes governing the entire system, from idea generation to execution. Even innovative organisations require processes to ensure that functions are carried out smoothly.
- Success - Unsuccessful organisations become stressful environments and it becomes difficult to encourage employees in these organisations. It is also necessary to assist employees to be more successful in their own tasks and departments. This might include having reward schemes and creating a sense of purpose in employees. When people feel like they are a part of something big, it motivates them to do their best.

A culture of innovation therefore means that an organisation holds internal assumptions, values, beliefs and management practices that foster developing new ideas into products, processes, objects and services (Aiman-Smith (2004).

3. Methods

A quantitative approach was used to conduct the study in order to achieve the objective, which was to establish the level of innovation culture in organisations and the relationship with employee retention. A field questionnaire survey was developed from a detailed literature review. The questionnaire contained questions regarding the characteristics of an organisation with innovativeness, employee satisfaction and retention, in three separate sections. With regard to innovation, a number of questions were asked to characterise innovativeness and focused on creativity at work, the freedom to make decisions and errors and the tendency of the organisation to develop new products. The questions on employee retention related to the extent to which employees would like to work at the company for a number of years (at least three years) or how often they seek employment in other establishments. The questionnaires were distributed by hand and email. Different organisations were targeted in order to draw a comparison in the innovative nature and employee retention between the sectors. The organisations included FMCG, Manufacturing and Construction, and Services companies. Out of a total of 500 questionnaires distributed, only 87 responses from three sectors were received and subsequently analysed using the Statistical Package for Social Sciences (SPSS). Descriptive and inferential statistics were the outputs from the analysis.

4. Findings

4.1 Demographic characteristics

Out of a total of 87 respondents, 64.4% were male and 35.6% were female. 55.3% of the respondents had been with their relevant organisations for less than five years, and the remainder of the respondents had tenure of between five and forty years.

4.2 Findings on innovative culture

Respondents were asked to rate the extent to which these were evident insofar as how innovative the organization was. Table 1 presents the findings on how respondents rated their organisations in terms of being innovative. It was found that all the organisations exhibited characteristics of an innovative organisation. Results showed more positive responses to the sixteen questions in this section as 55.6% agreed or strongly agreed to most of the questions. 26% of the respondents answered 'Neutral". Equally, the recorded response mode on most questions was determined to be 4. The standard deviation values were determined to be less than 1.0, indicating that the answers were mostly concentrated around the mean. Therefore, most respondents had similar views.

4,3 Findings on employee retention

Table 2 shows findings on employee retention. *I plan to remain in the organisation for at least three years* ranked highest with a mean score of 3.6. This value is between the neutral and the agree range, indicating that respondents were slightly unsure if they plan to stay in the enterprise for at least three years. With regard to the other four questions, respondents tended to disagree. The mean varied between 2.04 and 3.6, indicating that answers varied between Disagree, Neutral and Agree. The skewness was positive for most questions. Therefore, the distribution was skewed to the right, indicating that responses were mostly negative. The standard deviation was also determined to be small between 0.9 and 1.1, indicating a minimal variability. It can be deemed that the sampled employees are leaving the organisations.

Table 1: Findings on innovative culture

S/No	Element of innovative culture	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)	Mean Score	Mode	Std. Deviation
		1	2	3	4	5			
1	Employees in the organisation are an important source of information	0	2.3	4.6	40.2	52.9	4.44	5	.694
2	I am encouraged to ask questions when trying to perform a certain task	0	2.3	14.9	59.8	23	4.03	4	.690
3	I have control over my time management and how I carry out my functions at work	1.1	9.2	11.5	55.2	23	3.90	4	.903
4	The people in my department offer alternative solutions to problems/tasks	0	6.9	19.5	51.7	21.8	3.89	4	.827
5	I am allowed the opportunity to make decisions regarding specific tasks	4.6	11.5	10.3	59.8	13.8	3.67	4	1.008
6	I have an opportunity to be creative when solving problems in my current role	2.3	10.3	21.8	42.5	23	3.74	4	1.005
7	Management encourages me when I have problems carrying out certain tasks	4.6	6.9	19.5	63.2	5.7	3.59	4	.883
8	Innovative proposals are welcome in the organisation	2.3	12.6	26.4	47.1	11.5	3.53	4	.938
9	We continuously improve old products and raise the quality of new products	1.1	12.6	35.6	36.8	11.5	3.46	4	.907
10	Management and staff are tolerant to new ideas and differing views	1.1	14.9	31	48.3	4.6	3.40	4	.842
11	In comparison to competitors, our company has introduced more innovative products over the last five years	5.7	10.3	39.1	26.4	16.1	3.38	3	1.069

12	The organisation is a safe environment for ideas and employees are not penalised for new ideas that do not work	3.4	14.9	33.3	40.2	8	3.34	4	.950
13	Management actively seeks innovative ideas	5.7	16.1	37.9	31	9.2	3.22	3	1.016
14	We take delight in being spontaneous and are not afraid to laugh at our mistakes	5.7	20.7	31	34.5	8	3.18	4	1.040
15	I am rewarded when I am successful	5.7	19.5	39.1	27.6	8	3.13	3	1.009
16	Our company is often first to market with new products and services	9.2	17.2	40.2	19.5	13.8	3.11	3	1.135

Table 2: Findings on employee retention

		Strongly Disagree (%)	**Disagree (%)**	**Neutral (%)**	**Agree (%)**	**Strongly Agree (%)**	**Mean Score**	**Mode**	**Std. Deviation**	**Skewness**
		1	2	3	4	5				
1	I plan to remain in the organisation for at least three years	8	6.9	26.4	32.2	25.3	3.60	4	1.181	-.673
2	More than half the employees have been with the organisation for more than 10 years	1.1	14.9	40.2	28.7	12.6	3.38	3	.938	.058
3	Workers tend to leave the organisatio	5.7	31	32.2	23	6.9	2.94	3	1.033	.184

	n less often than expected									
4	As far as I know, my colleagues are not seeking employment elsewhere	11.5	32.2	18.4	29.9	5.7	2.86	2	1.156	.046
5	I rarely see new faces in the organisation	6.9	47.1	24.1	17.2	3.4	2.63	2	.971	.577

4.3 Relationship between innovative culture and employee retention

Given the level of innovativeness found in the organisations, it was expected that a considerable degree of employee retention will be visible. However, this was not the case. As can be seen from Table 2, it appears that many employees are leaving the organisations they work for.

Therefore, it can be deemed that innovativeness in an organization does not necessarily lead to expected level of employee retention. This result could mean that innovativeness in an organization does not influence the level of retention or turnover or they could be inversely related (Kesen, 2016). It could also mean that employees could leave a job because of factors besides the level of satisfaction from the job or work environment such as leadership style of overall culture (not necessarily innovative in nature) (Azanza et al., 2013).

5. Conclusion

The study sought to establish the level of innovativeness in different organisations including the construction industry as well as investigate the relationship between innovative culture of an organization and employee retention in the organisation. The study objective has been met. The outcome of the study however, did not reveal a relationship between innovative culture and employee retention. The sampled organisations had a high level of employee turnover, despite having high level of innovativeness. It was concluded then that there may be other factors contributing to employee turnover in the sampled companies. Further studies could therefore explore other factors in the sampled companies or related establishments.

The limitations of the study are worth mentioning. Firstly, the small sample size used may limit generalisation of the results. In addition, the generalisation of the findings may be limited since respondents were drawn from three industrial sectors in South Africa. Future studies could engage a larger sample to determine if a different result could be obtained. Furthermore, the study did not employ sophisticated statistical techniques to establish the relations. Further studies could use correlation and/or multiple regression analysis to determine the relationships among the factors considered.

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Achieving Zero Accident Vision through Management's Positive Health and Safety Culture

J. H. F. van Heerden[1], I. Musonda[2], C. S. Okoro[3]
[1,2,&3]School of Civil Engineering and Built Environment, Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment
University of Johannesburg
[2]imusonda@uj.ac.za; [1]chiomasokoro@gmail.com

Abstract
The high rate of accidents in the construction industry has been a concern for ages. The current paper highlights essential factors which can help to assure zero accidents in the construction sector. A review of extant literature from various sources including journal articles, and conference proceedings was conducted from databases including Elsevier, Science Direct, Google, Google Scholar and UJoogle**.** Extant studies, spanning over a 12-year period, were sought based on their possession of the relevant key words. It was found that training and induction by management chiefly influences health and safety (H&S) culture and the subsequent realisation of the zero accident goal/vision. Other management factors include leadership, commitment, involvement and planning/promotion of H&S standards. These factors include leadership, commitment, communication, involvement, promotion of H&S standards and training. This study adds to the body of knowledge on H&S performance and provides evidence for assuring zero accidents on construction sites.

Keywords:
construction industry, health and safety, management, safety culture, zero accident

1. Introduction

The construction industry is both economically and socially important (Yoon et al, 2013). However, despite its usefulness, the industry is riddled with accidents and fatalities to the detriment of organisations, society and any economy. The construction industry accounted for one third of all work fatalities in UK, and construction is Australia's third most dangerous industry (Chan, 2012). Accidents cause construction delays, cost overruns, bad reputation, loss of morale and confidence, penalties such as bans and closures, stakeholder dissatisfaction, and financial losses (Arachchige and Ranasinghe, 2015). One way to reduce the accident rates and consequent impacts is through imbibed organisational safety culture, especially with regard to management (Fu *et al.*, 2009). Although the industry is project-based and the rate of accidents varies from pone project to another, one thing that is common is that organisational culture influences the rate of accidents (H&S performance) (Yoon *et al.*, 2013).

Construction related accidents can be eliminated through culture which drives the implementation and practice of H&S and management (or managers) are at the forefront of H&S implementation (Yoon *et al.*, 2013; Fu *et al.*, 2014). Therefore, it is crucial to continuously research on ways to improve safety culture in organisations in order to reduce accident rates and gear towards a zero accident goal. The current paper reviews extant literature on H&S culture factors in a bid to highlight their importance in realising zero accidents in the construction industry. However, it focuses on management attributes which are essential in fostering H&S implementation.

Materials consulted for the review spanned over a period of 12 years, from 2006 to 2017. They were sourced from databases including Elsevier, Science Direct, Google, Google Scholar and UJoogle. The materials were included based on their possession of key words relevant to the study, including health, safety, zero accident, culture, construction industry. The findings are presented in the ensuing section.

2. Health and safety culture concept

The concept of culture was first established by Edward Burnt Taylor who defined it as, a complex whole that includes art, law, beliefs, morals, knowledge, any other capabilities and habits obtained by human (Okorie and Smallwood, 2010). The term H&S culture made its first appearance to the nuclear debate by the International Advisory Group of the International Atomic Energy Agency (IAEA) following the investigation of the Chernobyl disaster (Agumba and Haupt, 2009; Abdullah *et al.,* 2008).

It is essential to note that every organisation has some kind of H&S culture. It can either be positive or negative. According to Hughes and Ferrett (2008) the H&S culture of an organisation may be described as the development stage of the organisation in H&S management at a particular time. Abdullah *et al.* (2008); Saidin and Hakim (2007b) indicated that H&S culture can be labelled as a set of beliefs, attitudes, norms, technical and social practise that are alarmed with minimising the contact of individuals within and beyond an organisation to dangerous of injurious conditions. The IAEA (2017) defines safety culture as, 'that assembly of characteristics and attitudes in organisations and individuals which establishes that, as an overriding priority, safety issues at work receive the attention warranted by their significance'. According to Fernandez-Muniz *et al.* (2007), safety culture can be identified in two ways: As a set of perceptions, values, attitudes and patterns of behaviour with regards to the organisational safety, and a set of policies, procedures and practices relating to the minimisation of workers' contact with risks at all levels within the organisation, reflecting high level commitment to prevent accidents and illness.

Furthermore, H&S culture is said to be a subset of organisational culture that influences the attitude and behaviour of workers in relation to the H&S performance of an organisation (Wamuziri, 2006; Okorie and Smallwood, 2010).The outcome of these attitudes and behaviours should be measured and evaluated as it has been lacking in the construction industry. Through this measurement an indication can be given to whether the organisation owns a good H&S culture (Okorie and Smallwood, 2010).

Ahong *et al.* (2012) proposed that the H&S performance of an organisation is largely all about the vision of their managers and employees, meaning that H&S performance depends on people's ideas, thoughts and their understanding of the main factors influencing H&S performance. Moreover, safety culture connotes shared and learned meanings, experiences and interpretations of work and safety which guide peoples' actions towards risks, accidents and prevention. It includes people, processes and values which are most likely to hold when the safety concept is reinforced through positive means, and not just punitive actions (Chan, 2012).

This suggests that the core ideas of an organisation's H&S culture and management system determine the H&S performance. This can be seen with Heinrich's 1980 theory of accident causation, as shown in Figure 1. The centre represents the thought of mind, which are the core ideas needed by H&S management. This is where the organisation establishes a H&S management approach, management system and management measures. The safety engineering technology, equipment and facilities are then implemented (Fu *et al.*, 2014). Next to it, is the H&S management method, which aims to improve unsafe conditions of object, unsafe behaviour of people as well as the H&S performance within the organisation.

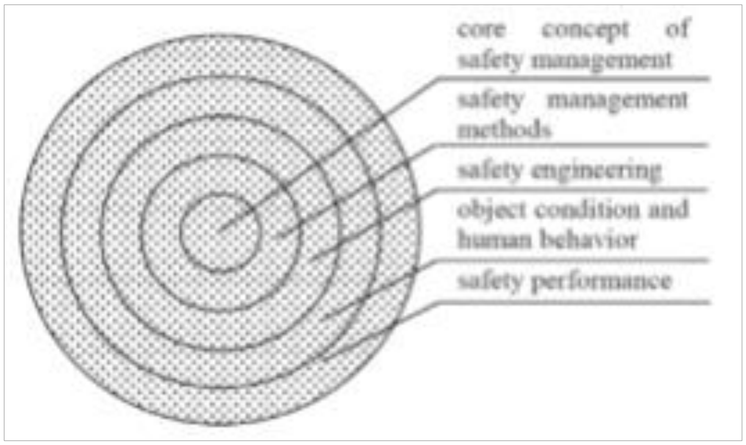

Figure 1: Definition of safety culture (Source: Fu *et al.*, 2014)

Therefore, H&S culture is important due to the fact that it forms the framework within which H&S attitudes develop and H&S behaviour is exhibited in order to gear towards achieving zero accidents.

3. Zero Accident Goal/Vision

The zero goal emerged in the 1990s and was constructed as both a philosophy and a target, the corporate and site voices developing alternative visions of zero in practice (Zwetsloot *et al.*, 2017). However, it has been argued that the concept is not clear since it can either be a “vision” or a “target”; the two are not interpreted the same and this opinion Varies from country to country (Sherratt, 2014).

Zwetsloot *et al.* (2017) opined that the zero accident vision is the ambition that all accidents are preventable or the commitment to create and ensure safe work and prevent all (serious) accidents in order to achieve safety excellence. On the contrary, targets, sometimes very ambiguous, may include reduction of fatalities by say 50% within a 10-year period, as was the case in Sweden (Zwetsloot *et al.*, 2017). However, positioning zero as a numerical target creates a goal to be achieved at a real point in time, which may not be achievable and therefore can be seen as simply reflective of wider industry practice in which people will be safe from harm (Sherratt, 2014; Smallwood and Emuze, 2016). The zero accident goal aspires to a world without severe and fatal accidents, or, in some versions, even without accidents at all, entails an allocation of responsibility, bearing in mind certain principles (Twaalfhoven and Kortleven, ibid.). These principles include that:

- All accidents can be prevented.
- Every accident is unacceptable.
- The management proactively advertises that every accident must be prevented.
- Learning from accidents is considered key to the success of the ZAV

In addition, H&S sees stakeholders and customers placed alongside those at physical risk on sites, all of whom become beneficiaries of a wider zero 'approach' (Sherratt, 2014). Therefore, for the zero accident goal to be achieved, hands-on participation and effort is required from all stakeholders.

However, for H&S culture to be operationalized in order to achieve the zero accident goal or vision, certain factors that form or shape it need to be identified. These are discussed in the next section.

4. H&S culture factors

According to Hughes and Ferrett (2008) all departments of an organisation must commit, before a positive H&S culture can be developed. H&S sees stakeholders and customers placed alongside those at physical risk on sites, all of whom become beneficiaries of a wider zero 'approach' (Sherratt, 2014). Eggort from all stakeholders is necessary in order to achieve the culture needed for the zero accident (transparent) goal (Smallwood and Emuze, 2016). Therefore, for the zero accident goal to be achieved, hands-on participation and effort is required from all stakeholders.

Literature identified management-related factors of health and safety culture attributed which are essential if zero accidents are to be assured. These are discussed in more detail hereunder.

4.1 Leadership

Leadership is one of the most influential factors in the development of H&S culture, as it has been recognised by safety experts and construction firms (Abdullah *et al.,* 2008). According to Saidin and Hakim (2007d) and Saidin *et al.* (2008), a positive H&S culture can be accomplished through co-operation between leaders and workers. Mwanaumo (2013) added the need to demonstrate leadership is to motivate and inspire workers to work towards achieving a specific goal, by notifying the workers about the significance of H&S. Leadership, as well as the initial impetus to begin the quest for reduced injuries on site, leadership at all levels set directions such as the ergonomic focus, changes in work organisation, and individual behaviour (Young, 2014). It also has a high level of influence on incident investigation accountability (Kim and Gausdal, 2017). Specific transformational leadership behaviours, such as encouraging workers to work safely and discussing safety openly, maintaining and initiating a safe working environment, listening to safety concerns, and so on are effective in influencing positive attitudes and behaviors towards safety-critical work tasks, as well as safety compliance and participation (Kim and Gausdal, ibid.).

4.2 Effective Communication

Many problems in H&S arise due to poor communication (Hughes and Ferrett, (2008). Communication according to Saidin and Hakim (2007d) and Saidin *et al.* (2008), involves all aspects of work in an organisation and is able to link all entities at every level to H&S aspects. Efficient H&S communication according to Musonda (2012) may entail: feedback and formal reporting systems; H&S briefings; risk control information; clear H&S policy statements and worker involvement in planning and review of H&S. The culture action must communicate company values that are expected and supported by the company (Mwanaumo, 2013:46). Successful communication must ensure 'relevant' information to respective organisational levels (not a one-size fits-all strategy), and allow for 'decentralised' initiatives (Zwetsloot *et al.*, 2017).

4.3 Commitment

According to Hughes and Ferrett (2008:59), commitment must come from top management. They further stated that commitment will result in higher levels of motivation and commitment throughout the construction organisation. This statement is supported by Saidin and Hakim (2007d); Saidin *et al.* (2008) as they state that leaders, who consider the notion and needs of workers, will be able to increase the work quality and motivation level. Commitment according to Misnan and Mohammed (2007) can be achieved through:

- A Positive attitude towards H&S;
- Promoting H&S in the organisation at all levels;
- Providing financial support, so that H&S can be implemented and;
- Supporting H&S development and implementation.

The effectiveness of H&S committees can also be seen a reflection of management commitment (Musonda, 2012:65). The purpose of H&S committees is to: develop safety values and establish safety as the main goal to be achieved, improve the environment (Saidin and Hakim, 2007d and Saidin *et al.,* 2008).

4.4 Involvement

Involvement of leaders and workers in H&S management is an important indicator when it comes to achieving a positive H&S culture (Saidin and Hakim, 2007d; Saidin *et al.,* 2008 and Teo and Ling, 2006). The involvement, input and participation in H&S management processes leads to empowerment and, in return, helps the organisation's H&S management plan and decisions, to be driven by purpose (Mwanaumo, 2013). To be involved in H&S management according to Musonda (2012) is to be:

- Present in H&S activities, meetings and planning sessions;
- Involved in management contribution towards training;

4.5 Promotion of H&S standards

According to Hughes and Ferrett (2008) every worker within the organisation needs to understand the standards of H&S, expected by the organisation, and the individual role of achieving those standards. It was further indicated that H&S standards cover all aspects of the organisation, such examples are:

- The design and selection of premises, plant and substances;
- Recruitment of contractors and employees;
- Control of work activities including risk assessment;
- Competence, maintenance and supervision and;
- Emergency planning and training.

Long-term safety planning, designing for construction H&S, contractor planning , risk assessment and inspiring innovative approaches will help to ensure that H&S standards are promoted with an aim to achieving zero accidents (Smallwood and Emuze, 2016; Zwetsloot *et al.*, 2017)

4.6 Training

Training according to Saidin and Hakim (2007d); Saidin *et al.* (2008) and Hughes and Ferrett (2008) is a very important part of H&S culture and it is also a legal requirement. The effectiveness of H&S training has been proven to uplift awareness and knowledge of workers on safe working culture. Training is critical when it comes to H&S performance (Fernandez-Muniz *et al.*, 2007). Othman *et al.* (2008) and Hughes and Ferrett (2008) identified different types of training, namely: induction training; job-specific training; supervisory and management training; specialist training.
Induction training - This type of training is normally provided to new employees, trainees and contractors. Such training will cover items such as quality, conditions, pay and H&S.
Job-specific training - This type of training ensures that all employees perform their jobs in a safe manner. This training is a form of skill training and is best done 'on the job'.

Supervisory and management H&S training - This type of training is similar to that of induction training, but more in depth with detailed treatment of H&S law. This training focus on all level of management as it keeps everybody informed with the legal requirements with regard to H&S, accident prevention techniques and it inspires members of the organisation to monitor H&S standards.

Specialist H&S training - This type of training is required for activities that are not related to a particular construction project, but to an activity. Examples of such training may include: scaffold inspection; first-aid; fire prevention; overhead crane operations *etcetera.*

All these are necessary to gain competence which is vital on the job. Competence is an important factor derived from aspects such as education and training (Fernandez-Muniz *et al.*, 2007). Moreover, training on "zero harm" concept contributes to making an organisation an "accident free" or "zero-harm" enterprise (Chan, 2012).

5. Summary and Concluding Remarks

The construction industry is notorious due to its poor safety record. One of the ways which has been advocated to reduce accidents and fatalities and move towards achieving a zero-accident target is through total safety culture. Safety culture driven by management is even more effectual because they spearhead implementation. The current study therefore sought to identify management factors or attributes which drive safety culture and the vision of zero accidents in the construction industry.

From Table 1, which is a matrix of the reviewed literature and emerging factors, it can be seen that training appeared to be the most important H&S culture factor. This suggests that the construction industry needs to intensify training and awareness about zero accidents. The task of managing and implementing H&S systems and programs cannot also be left up to management alone. The organisation establishes a H&S management approach, management system and management measures but these also rub off on the behaviours and attitude of workers, which may be nonchalant, participatory or proactive. Therefore, workers' participation is crucial if zero accident goal or vision is to be achieved. All construction stakeholders must be involved in identifying ways to intensify training and induction programs in order to educate, not only the workers but all stakeholders on the importance of attaining zero accidents.

Table 1: Factors of health and safety culture

Literature source	Leadership	Effective communication	Commitment	Involvement	Promotion of H&S standards	Training
Teo & Ling (2006)				x		
Fernandez-Muniz *et al.* (2007)						x
Misnan & Mohammed (2007)			x			
Saidin & Hakim (2007d)	x	x	x	x		x
Abdullah *et al.* (2008)	x					
Hughes & Ferrett (2008)		x	x		x	x
Saidin *et al.* (2008)	x	x	x	x		x
Othman *et al.,* 2008)						x
Chan (2012)						x
Musonda (2012)	x	x	x	x		

Haupt *et al.* (2013)						
Mwanaumo (2013)	x	x		x		
Smallwood & Emuze (2016)					x	x
Zwetsloot *et al.* (2017)	x	x		x	x	
Total/frequency	**6**	**6**	**5**	**6**	**6**	**7**

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Conflict Management in Construction Industry: A Review Paper

Tauha Hussain Ali
Professor, Department of Civil Engineering, Mehran University of Engineering & Technology, Jamshoro
sacharvi2@gmail.com

Shabir Hussain Khahro
Lecturer, Department of Engineering Management, Prince Sultan University, Saudi Arabia
shkhahro@gmail.com

Nafees Ahmed Memon
Professor, Department of Civil Engineering, Mehran University of Engineering & Technology, Jamshoro
nafees.memon@faculty.muet.edu.pk

Muhammad Ali Moriyani
Post Graduate Student, Mehran University of Engineering & Technology, Jamshoro
mamoriyani@gmail.com

Fida Hussain Siddiqui
Lecturer, Department of Civil Engineering, Mehran University of Engineering & Technology, Jamshoro
fida.siddiqui@faculty.muet.edu.pk

Qasim Hussain Khahro
Post Graduate Student, Mehran University of Engineering & Technology, Jamshoro
qhkhahro13@gmail.com

Abstract
Construction industry plays a key role in any country's development. It contributes significantly in the GDP and job market of the country. It is aimed that a successful project should be carefully planned, designed and constructed in a way that it should meet the project goals and above all client's satisfaction. Various factors are involved in achieving a successful project and managing conflicts is a key one. This paper aims to investigate the existing literature available on conflict management in construction industry. A detailed literature analysis has been made for this research. In later stages, a qualitative survey followed by an SPSS analysis has also been made. The study concludes that construction projects are getting complex to meet client needs and sustainability guidelines. A total number of 93 factors are identified and ranked at the later stage of this study. Lack of proper supply chain in construction projects lead to conflicts in this industry, so this has been a topic of research interest for many researchers. This paper helps the practitioners of this industry to make necessary policies and frameworks to properly manage conflicts in construction projects.

Keywords
Conflict, Construction Industry, Dispute, Project Life Cycle

1. Introduction

Construction industry has been experiencing various challenges. Today, client needs change and assuring sustainability & socio-economic features in construction industry; the projects are becoming complex. In such scenarios, numerous stakeholders are involved in the projects. Hence, in such a busy environment where various stakeholders are busy in accomplishing the

tasks assigned and its obvious in such case that a minor mistake or gap in communication; can lead to conflict. Conflict leads to many problems including delay, cost overrun, decreased productivity, more disturbed relationships within stakeholders and so on.
The construction has a complex supply chain with several units involved. There is a contractual relationship between all the main participants. Due to the potentially large number of people involved in the construction process and their different organizational goals and objectives, the potential for variation, external factors, changing conditions and different expectations pose the risk of misunderstandings, misunderstandings and ultimately misunderstandings and conflicts.

Thus, this paper provides an in-depth investigation of conflict, its causes, sources and resolution techniques for conflict management. This paper summarizes the existing body of knowledge available on conflict management in construction industry. It can help the practitioners of construction industry to design & modify their policies and practices in managing this centric issue faced by the industry. It will enhance a healthy professional working environment in construction industry as all parties' rights will be addressed and acknowledged.

2. Literature Research

A comprehensive literature assessment was conducted for this research. The literature covers almost the last two decades of data for conflict management research for the construction industry. Detailed mapping is done in the next phase, which provides a clear view of the features. The construction industry involves the number of people from different regions who have different expertise and different cultures and languages, resulting in poor communication between the people involved in a project, which ultimately leads to conflict between different parts. In such cases, projects are not completed within specified time, cost and allocated budget (Khahro & Ali 2014). Therefore, it is very important to deal with conflicts at an early stage in order to complete a project.
(Femi 2014) defines conflict as an argument in a question about project operations, usually as a result of a discussion of differences between two or more parties, understanding the situation. Conflict occurs when a person's behavior interferes with or interferes with another action. (Awakul 2002) & (Saud Almutairi 2015) define conflict as a process in which one party perceives that one's interests are opposed or otherwise affected. According to them there wouldn't be conflicts in the perfect construction world, but perfect construction world does not exist. (Farooqui & Azhar 2014) described construction projects in a very complex and dynamic environment where unpleasant events such as claims usually occur. (Li et al. 2012) also pointed out that the confrontations and disputes may arise due to the diverse and conflicting interests of the stakeholders.
(Farooqui et al. 2012) mentioned that less educated and professional staff is running construction sites fail to do their work correctly or efficiently within given time period, then dispute occur. (Yusof et al. 2011) specified that conflict as a state of opposition, disagreement between persons or a group of persons over ideas, interests, beliefs, feelings, behavior or goals. (Gitau 2016) concluded that project team must ensure the effective coordination and communication between the team members of the project to avoid conflicts. (Wei et al. 2016) also suggested that the local issues should be investigated and must be addressed directly by the project managers to avoid conflicts. (Rauzana 2016) suggested that the conflicts between the project participants must be managed effectively to avoid losses. Hence, it is of extreme importance to identify the probable causes of those conflicts in order to prepare a good management plan to complete any project as a successful endeavor(Elmabrok et al. 2016). Annexure 1 shows a detailed mapping of factors identified in literature review.

3. Research Methodology

A detailed literature review has been made for factor identifications in this research. The identified factors were processed through a short pilot study. Experts' opinion during pilot study is amended in final set of questionnaire which was send to numerous practitioners working in construction industry via hard mail and emails. The respondents were requested to share their experience to assist the priority of factors for conflict management in general and with specific reference to construction industry of Pakistan. Finally, 159 questionnaires were considered for this research which was received during data collection period.

Average Index (AI) method has been successfully used for data analysis of such decision-making problems. Therefore, same is used for data analysis of this paper. Average Index is indexed as follows:

$$\text{Average Index} = \left[\frac{\sum_{i=1}^{5} a_i x_i}{5\sum_{i=1}^{5} X_i} \right]$$

Where, ai = Constant expressing the weight given to i, Xi = variable expressing the frequency of the response for:

4. Results & Discussion

It has been observed that few researchers did a detailed analysis of conflict management throughout project life cycle. This research is an addition to the existing body of knowledge for conflict management in construction projects in general and specifically for Sindh, Pakistan. Table 1 shows the most frequent causes of conflicts occur in construction industry.

Table 1: Most Frequent Causes of Conflicts in Construction Industry

Frequent Factors	Rank
Poor communication/ lack of communication/ Miscommunication	1
Failure of payment/ Delay in payments/ Payment delays /Delay in progress payment by owner	2
Lack of communication procedures/ Lack of communication between construction parties/ practitioners	2
Design errors and specification/ Design errors made designer/ Change due to design errors by designer/ Errors and omissions in design	3
Differing site conditions/ Site conditions	4
Unclear contract terms/ Poorly written contract/ Ambiguities in contract documents/ Excessive contract variations	4
Changes in work/ Change of scope of works as a result of changes in client's requirements/ Change of scope of works due to client requirement instability	4
Change orders/ excessive change orders/ change orders by owner during construction	4
Inadequate contractor's experience/ Inexperienced contractors/Inadequate contractor experience causing error/ incompetent contractor	5
Poor estimation practices/ Inaccurate estimation practices/ Estimation errors/ error of pricing or costing	5
Risk allocation/ Unclear risk allocation/ Unfair risk allocation/ imbalance in risk allocation	5
Errors in drawings/Insufficient working drawing details/ Defective drawings	5
Weather / Adverse weather conditions/ hot weather effect on construction activities	5
Mistakes in design/ Errors in project documents/ Mistakes and discrepancies in design documents	6
Negligence	6

Errors in bill of quantities/ Inaccurate bill of quantities	6
Errors in specification/ Use of out dated specifications/ Inadequate/ incomplete specifications/ defective specifications	6
Financial failure of contractor/ Main contractor financial problems/ difficulties in financing the project by contractor	6
Poor decision making/ delay in decision by owner/ slowness in decision making process by owner	6

In light of the findings of Table 1 the key factors which have profund influcence in creating conflicts have been identified. It has been oberved that "Poor communication/lack of communication/ Miscommunication" is one of the major cause leading to conflict. Second in the line, two factors i.e "Failure of payment/ Delay in payments/ Payment delays /Delay in progress payment by owner" and "Lack of communication procedures/ Lack of communication between construction parties/practitioners" both have equal influence in causing conflict in the construction industy. Design errors and specification/ Design errors made designer/ Change due to design errors by designer/ Errors and omissions in design" are ranked at third influence and so on for others.

To get a clear view point, Figure 1 shows a pilot analysis of key causes leading to conflicts in construcion industry. Following 8 causes from body of 93 causes have very substantial contribution in causing conflicts.

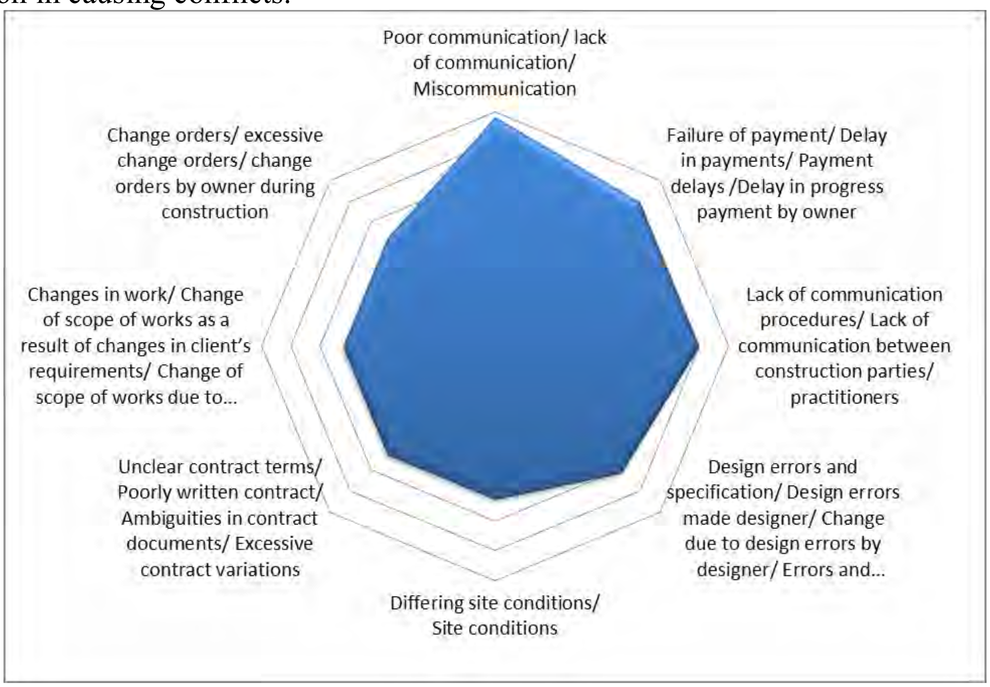

Figure 1: Most Critical Causes of Conflicts in Construction Industry

All identified causes of conflicts in this research are categorized in to 10 different groups and these groups are called as conflict causual areas. Following Table 2 shows the most important conflict causual areas as per project phases.

Table 2: Rank of Conflict Causal Area Leading to Conflicts at different Stage of Project

Conflict Area with Stage	Rank
Delays in Payments during Construction Stage	**1**
Poor Communication during Construction Stage	**2**
Excessive Contract Variations during Construction Stage	**3**
Delays in Payments during Post Construction Stage	**4**

Public Interruption during Construction Stage	**4**
Differing Site Condition and Limitations during Construction Stage	**5**
Contractual Claims during Construction Stage	**6**
Design Errors during Design Stage	**7**
Errors in Project Documents during Construction Stage	**8**
Design Errors during Construction Stage	**9**
Contractual Claims during Post Construction Stage	**10**
Multiple Meanings of Specifications during Construction Stage	**11**
Differences in Evaluation during Construction Stage	**12**
Differences in Evaluation during Post Construction Stage	**13**
Public Interruption during Post Construction Stage	**14**

As per the findings in Table 2, the most important conflict causal areas as per project phases are identified. It is analyzed that delays in Payments during construction stage is one of the major causal area and project stage. Similarly, Poor Communication during Construction Stage is ranked at second and Excessive Contract Variations during Construction Stage" stands at thrid major causual area and project phase.

In the last phase of this research, a mapping of suitable conflict resolution techniques has been made in relation with project life cycle as mentioned in Table 3.

Table 3: Rank of Conflict Causal Area with Project Stage

Remedial Measure	Pre Design Phase	Design Phase	Construction Phase	Post Construction Phase
Collaborating	1.7	2.1	2.8	1.5
Compromising	1.6	2	2.6	1.4
Competing	1	1.2	1.6	1
Avoiding	1.2	1.2	1.5	1.1
Forcing	1.1	1	1.3	1
Smoothing	1.7	1.6	1.8	1.6

5. Conclusion & Suggestion

Reviewing a vast literature including qualitative, quantitative surveys and case studies from various construction industries of the world led to identification and ranking of factors initiating conflicts. Survey and analysis over the data collected and scrutinized in Pakistan. It is concluded that Poor communication, Delay in progress payment by owner, Lack of communication between construction parties, Errors and omissions in design are the key reasons of conflicts in this industry. Current research abridged the factors into conflict causal groups and found that Delays in Payments, Poor Communication, and Excessive Contract Variations during construction stage are the leading categories causing conflicts. Further, a qualitative study was conducted by various stakeholders to highlight suitable remedial approaches. Collaborating and compromising have been found to be the most suitable solutions to avoid conflicts. It is recommended and suggested to the policy makers of the concerned industry to review the respective literature and a little addition to it in the current research form; find some grace as per the analyzed remedial resolutions in pre-construction, during and post-construction phases. The organizations consisting of numerous stakeholders from all levels of construction industry are shaped up to deal with such situations (conflicts resolution).

6. Acknowledgement

This paper is part of a master's research project conducted at Civil Engineering Department, Mehran University of Engineering & Technology (MUET), Jamshoro. This is a self-funded research project. The authors are thankful to MUET for providing platform to conduct this research. The authors also thank Prince Sultan University, Riyadh, Saudi Arabia for providing scholarly support throughout this research.

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S#	Causes	Pinar (2016)	Ibrahim (2016)	Elmagdobi (2016)	Anita (2016)	Ejohwomu et al. (2016)	Remon et al. (2016)	Vachara and lakhena (2015)	Almutairi et al. (2015)	Faizan and Nadeem (2015)	Sigitas and Tomas (2014)	Rizwan et al. (2014)	Emre and Pinar (2014)	Femi (2014)	T.H.A and S.H.Khahro (2014)	Rizwan et al. (2012)	Borvorn (2011)	Jaffer et al. (2011)	Peter et al. (2010)	Tommy et al. (2006)	Acharya et al. (2006)	Saadi a asaf (2006)	Cheryl et al. (1994)	Nency	Total
1	Lack of funds			1		1									1										3
2	Failure of payment/ Delay in payments/ Payment delays /Delay in progress payment by owner	1	1									1	1		1			1				1		1	8
3	Differing site conditions/ Site conditions		1						1				1		1						1	1			6
4	Unclear contract terms/ Poorly written contract/ Ambiguities in contract documents/ Excessive contract variations	1	1										1		1		1		1						6
5	Changes in work/ Change of scope of works as a result of changes in client's requirements/ Change of scope of works due to client requirement instability	1		1		1									1					1			1		6
6	Contradictory and errors of information in contract documents/ Violating conditions of the contract	1															1			1					3
7	Plans and specifications that contain errors/ Differences in interpretation of plans and specifications	1	1																						2
8	Poor communication/ lack of communication/ Miscommunication								1	1		1		1	1			1			1	1		1	9
9	Change orders/ excessive change orders/ change orders by owner during construction		1						1								1				1	1	1		6
10	Inflation / market inflation		1														1				1				3
11	Design errors and specification/ Design errors made designer/ Change due to design errors by designer/ Errors and omissions in design				1		1	1	1				1		1						1				7
12	Lack of communication procedures/ Lack of communication between construction parties/ practitioners		1	1	1				1				1		1		1			1					8
13	Evaluation of quality and quantity of completed works/ Evaluation of completed works		1														1								2
14	Accuracy of project cost estimate		1														1								2
15	Mistakes in design/ Errors in project documents/ Mistakes and discrepancies in design documents		1												1		1					1			4
16	Negligence			1						1					1						1				4
17	Inadequate contractor's experience/ Inexperienced contractors/Inadequate contractor experience causing error/ incompetent contractor		1				1													1	1	1			5
18	Poor estimation practices/ Inaccurate estimation practices/ Estimation errors/ error of pricing or costing		1		1				1									1						1	5
19	Cash problems during construction		1																						1
20	Poor financial projection on client's side			1		1									1										3
21	Risk allocation/ Unclear risk allocation/ Unfair risk allocation/ imbalance in risk allocation											1	1		1					1	1				5
22	Errors in bill of quantities/ Inaccurate bill of quantities			1											1		1			1					4
23	Liquidated damages	1																							1
24	Wrong interpretation of reports			1																					1
25	Lack of necessary permits from authorities			1																					1
26	Errors in drawings/Insufficient working drawing details/ Defective drawings			1						1					1		1							1	5

27	Excessive claims by contractor/ Exaggerated claims			1								1													2
28	Delays in evaluation processes			1																					1
29	Claim of time extensions	1																							1
30	Cheap design hired instead of quality					1									1										2
31	Design changes by owner/ Design function change due to client's requirement						1	1																	2
32	Poor coordination				1							1													2
33	Errors in specification/ Use of out dated specifications/ Inadequate/ incomplete specifications/ defective specifications			1									1		1									1	4
34	Language barrier/ Language problem			1											1										2
35	Professional culture problems			1											1										2
36	Poor public relationship between project people and the public					1									1										2
37	Wrong interpretation of site investigation					1									1										2
38	Unrealistic construction schedules/ Unrealistic contract durations											1					1								2
39	Calculation of incorrect work progress				1																				1
40	Lack of experience of consultant				1																				1
41	Financial failure of contractor/ Main contractor financial problems/ difficulties in financing the project by contractor												1				1				1	1			4
42	Weather / Adverse weather conditions/ hot weather effect on construction activities												1				1				1	1	1		5
43	Poor decision making/ delay in decision by owner/ slowness in decision making process by owner													1			1				1	1			4
44	Inexperience of designer/ inadequate design team experience					1																1			2
45	Social, religious and cultural factors/ Cultural differences						1								1					1					3
46	Owner financial problems/ financial failure of owner						1														1				2
47	Change of scope/ Scope variations									1			1						1						3
48	Public Interruption/ Obstructions by local people/ local people interruption								1						1						1				3
49	Poor financial control on site		1																						1
50	Lack of trust													1											1
51	Laborers personal conflicts/ labour disputes/ union strikes						1														1				2
52	Scope change by owner							1																	1
53	Change in material specification by owner							1																	1
54	Schedule change by owner							1																	1
55	Corruption								1																1
56	Resource availability									1															1
57	Unfriendly attitudes									1															1
58	Change in specifications by designer							1																	1

59	Schedule change due to poor planning from contractor side/ ineffective planning and scheduling of project by contractor							1														1			2

Annexure 1: Mapping of Identified Causes

Diffusion of innovations approach to explore sustainable development in the UAE built environmet

Dr Amna Shibeika
(Assistant Professor, UAEU, Al Ain, Aby Dhabi, UAE)

Abstract
Sustainable development is important for the UAE, not just to follow global ongoing efforts to reduce consumption of and preserve resources, but also because of the breath-taking development for the UAE economy since its formation in 1971, which is coupled with fast development in buildings and real estate sectors. This research directly addresses the UAE government policy for innovation and sustainable development by providing better understanding of the processes for innovative sustainable development of buildings. Environmental assessment methods such as Estidama and its related Pearl Building Rating System (PBRS) has the potential to play the role of market changers for the spread of sustainable development practices in the built environment, however, most of the existing research in assessment methods is focused on either comparing different methods, or adapting existing and developing new methods for specific contexts. And while a lot of research is focused on the outcomes of the assessment, very little is concerned with the assessment process itself and its effect on design and construction processes and practices. A scoping study is developed, which adopts diffusion of innovations theory as the analytical tool, and interpretive content analysis of key policy documents and guidance as the research method to explore the diffusion of sustainable development of the built environment in the UAE. Early findings indicate the role of Pearl rating system as the foundation for sustainable development in Abu Dhabi built environment, and reveal multiple two-way communication channels for diffusing sustainable development policy and practices. Next steps for the research to further explore these findings through in-depth case studies of the adoption of PBRS in projects in UAE are presented.

Keywords
Adoption, building assessment, design management, innovation, sustainability

1. Introduction

Reducing energy consumption and conserving natural resources is an important topic, which is currently receiving universal interest. Governments across the globe have been developing strategies and policies to address issues such as: climate change, carbon emission, and the use of more sustainable sources for energy (United Nations 1992). In the UAE, the government vision is to be at the forefront of innovative sustainable development by 2021. The UAE national innovation strategy, which was published in 2015 places great attention on building an innovation friendly ecosystem, and creating a culture of innovation among individuals, firms and the public sector to aid sustainable development of the country to reflect its economical growth, which is happening in a breath-taking rate since its independence in 1971 (Ministry of Cabinet Affairs 2015).

The UAE investment in innovation is estimated to be between AED 10 and 14 billion yearly, AED 7 billion of which is in R&D (Ministry of Cabinet Affairs 2015). However, emerging research in the transition of the UAE from oil-based towards knowledge-based and innovation-driven economy has found that despite extensive spend on research and development (R&D), the UAE still requires more work to catch countries such as Brazil, Russia, India and China (Gackstatter, Kotzemir and Meissner 2014). This calls for more government-academia collaboration, and more research to investigate the intersection between government policy and sustainable development as it unfolds in practice, or in other words how government policy in innovative sustainable development is actually realised? Thus, this research seeks to address the UAE governmental efforts towards more innovative and sustainable development by focusing on the building and construction sectors which are directly related to the seven main sectors identified by the UAE national innovation strategy to lead innovation at the national level, these are: renewable and clean energy, transportation, technology, education, health, water and space (Ministry of Cabinet Affairs 2015).

The UAE construction and real estate sectors are ones of the fast growing globally, they account for around 20% of the UAE total GDP (2014). The growth in both sectors is coupled with major consumption of resources, which highlights the UAE building industry as a fertile environment to explore the provision of sustainable development. Hence, the focus of this research on sustainable development of the UAE built environment, through the investigation of the adoption of environmental assessment methods for sustainable buildings and infrastructure in the UAE.

In the following sections, literature in environmental assessment tools and methods is reviewed, diffusion of innovations theory is introduced as the conceptual lens for answering the research question, and then early findings of this scoping study are discussed. The paper finally concludes with final discussion and future steps for this research.

Background to environmental assessment tools and methods

In response to government policy in sustainable development, buildings, infrastructure and urban developments are required to meet certain performance criteria in relation to different design, construction, and operation aspects as it intersects with its surrounding natural environment. This has resulted in the adoption of different processes, tools, and methods by design and construction professionals in their efforts to demonstrate sustainable development of the built environment. These tools and methods often referred to as building environmental assessment tools and methods, which provide objective evaluation and assessment of the performance of the developed facility in relation to its environmental impact (Cole 2005).

The growing literature, which focuses on building environmental assessment tools and methods has found that these tools and methods vary on focus and scope based on: types of buildings, users of the tools, the phases within the lifecycle of the assessed building, databases of the tools, and the form of the results of the use of the tools (Haapio and Viitaniemi 2008). Environmental assessment tools and methods are mostly developed by research institutes and adopted by local authorities and municipalities as guiding frameworks for sustainable design and construction. Despite majority of the tools and methods favoring the environmental aspect over the social and economic aspects of sustainability, but building environmental assessment tools and methods are still seen as *market changers* for more sustainable built environment (Cole 2005).

Scholars often differentiate between assessment tools and assessment methods. In one hand, there are assessment tools in the form of software tools and plug-ins, which provide architects and engineers with interactive opportunities to explore different options and scenarios in relation to environmental performance of different building components, materials, or elements. In the other hand, there are methods for assessment of buildings or facilities as a whole, following the assignment of scores or points to different performance criteria. Building Research Establishment Environmental Assessment Method (BREEAM) was the first assessment method of this type, it was introduced in the UK in 1990, then followed by a wide range of similar methods such as Leadership in Energy and Environmental Design (LEED), which was introduced by the US Green Building Council in 2000.

Cole (2005) has defined assessment tools as *the techniques that predicts, calculates or estimates one or more environmental performance characteristics of a product or building*; and assessment methods as *the frameworks that organize or classify environmental performance criteria in a structured manner with assigned points of weightings* (Cole 2005:456). This research adopts Cole's definition, and focuses on Estidama framework for sustainable development and its associated Pearl Building Rating System (PBRS), which is currently used to assess buildings in the emirate of Abu Dhabi in the UAE.

Most of current literature on assessment methods is focused on two aspects: First, there are studies that focus on comparing the different available methods (Happio and Viitanieme 2008) and their applications on different contexts (Cole and Valdebenito 2013). Research addressed Estidama and PBRS follows this stream, as it often tends to compare it with international assessment tools such as BREEAM and LEED (Al Salmi, Al Kadi and Leao 2013; Khogali 2016). Second, there is a large literature which has been focusing in developing new methods to address specific regions, for example the development of assessment methods in Saudi Arabia (Banani et al 2016), again most of the work of this stream is based on comparing and contrasting different elements of the assessment methods with little focus on its use by project teams. Critiques of this literature call for further investigation of the factors, which influence the choice of the assessment methods.

While most of the environmental assessment methods are voluntary, a lot of governments around the world are increasingly mandating these methods for government projects, thus, it would be useful to compare between voluntary adoption by the private sector for example with publicly funded projects which has to follow mandated methods. Furthermore, the development of buildings is a creative complex process, which involves: various stakeholders and team players, different stages and phases, and wide range of resources and information (Emmitt 2014). The adoption of any environmental assessment method in either a voluntary or mandated base needs to be realized and managed within this complex process of design and construction, which in itself is a big challenge.

Growing literature is investigating different project characteristics that influence sustainability outcomes in the form of scores or ratings resulting from environmental assessment methods. Mollaoglu-Korkmaz, Swarup and Riley (2013) investigated the influence of project delivery methods on the LEED rating of 12 commercial buildings in the US and found that higher levels of integration found in design-build and construction management delivery methods has led to higher sustainability outcomes, however, they also found that there are important factors which led to greater integration and consequently higher rating regardless of the delivery method; these factors are: design charrette, project team member's compatibility, and commitment to project sustainability goals. In a similar attempt to reveal the intersection of environmental assessment methods with design and construction project work, Schweber and Haroglu (2014) examined the fit between BREEAM and design processes in 8 commercial buildings in the UK, they found that prior experience with environmental assessment was key for sustainability outcome.

This literature is useful for this research as it turns the attention to important issues related to the adoption of environmental assessment methods, such as: integration, communication, and collaboration processes, as well as the role of assessors or key project professionals as champions for the adoption of the different practices leading to improved sustainability outcomes.

Diffusion of innovations theory as an analytical tool

Diffusion of innovations theory is very useful for explaining how individuals and organizations adopt and implement a new process or technology such as energy assessment methods. It is an established theory which was started in in the 1940s and 1950s within rural sociology and education, and then gradually emerged within other research traditions such as: anthropology, early sociology, public health and medical sociology, communication, marketing and management, geography and general sociology (Rogers, 2003). Diffusion of innovations theory have been adopted as a guiding analytical theory by construction researchers to investigate a wide range of issues such as: the specifications of building materials (Emmitt 2001); the spread of digital innovations in construction projects and firms in Australia (Peansupap and Walker 2005), America (Mitropoulos and Tatum 1999, 2000), and the UK (Shibeika and Harty 2015); as well as the adoption of renewable technologies in the UK housing sector (Lees and Sexton 2013).

Diffusion of innovations theory pioneered by Rogers considers four important constructs: the innovation itself, the communication channels through which knowledge about this innovation spread, the social system within which diffusion occur, and the adoption process as it unfolds over time (Rogers 2003). Research related to the diffusion of innovations in construction has advanced these constructs to provide more context-specific explanations; for example, one innovation in construction could lead to wakes of other innovations across projects and firms (Bolland et al 2009), this is due to the project-based collaborative nature of construction work. The concept of communication channels is viewed from the point of the network effect of the highly collaborative, and information intensive construction work (Larsen and Ballal 2005), to the consideration of the construction innovation itself as the communication channel as in the case of the diffusion of BIM technologies in a UK engineering firm (Shibeika and Harty 2015). Most importantly, the innovation adoption process in construction is found to be non-linear following different paths across multiple organizational levels (Shibeika and Harty 2015). Champions are also found to be key for adoption and diffusion of innovations in construction; their roles could range from specification architects (Emmitt 2001), to technology managers (Shibeika and Harty 2015) to energy assessors (Schweber and Haroglu 2014).

This research is a scoping study for a new two-years research project to investigate sustainable development in the UAE built environment. It adopts diffusion of innovations theory as analytical tool, and interpretive content analysis of key policy documents and guidance as the research method to explore the diffusion of sustainable development framework “Estidama” and its associated assessment system PEARL in Abu Dhabi.

Preliminary findings

The content analysis of key policy documents , related to Estidama framework has revealed the following:

Estidama as the infrastructure for sustainable development of the built environment in the UAE

In the UAE, Estidama is the sustainability program pioneered by Abu Dhabi Emirate, it is the first of its kind in the Middle East region, to ensure *well-integrated built environment with efficient resources, reliable and comfortable to inhabit buildings* (Abu Dhabi Urban Planning Council 2010). Developed by the Urban Planning Council (UPC) of Abu Dhabi, Estidama promoted as the *symbol of an inspired vision for governance of sustainable buildings from inception, to design, through construction, to operation* (Abu Dhabi Urban Planning Council 2011). Not itself a rating system, Estidama is rather a methodology to address the four pillars of sustainability: environmental, economic, cultural and social.

Estidama is different from other international systems such as BREEAM and LEED which draw from existing building codes and legislations, while Estidama has influenced and induced the development of the UAE building codes (Al Salmi, Al Kadi and Leao 2013). The realization of Estidama program is driven by the Pearl Building Rating System (PBRS), which was first introduced in 2010. From September 2010 all new buildings are required to achieve Pearl 1 rating, while all new government-funded buildings are required to achieve Pearl 2 rating. This mandate has led to the alignment of PBRS with other Abu Dhabi Development and Building Codes, and UPC embedding Estidama elements as the minimum sustainability requirements for the approval of developments. By 2013 More than 400 buildings were rated under the system About 10,000 villas are rated, about 7,500 of which have at least two pearls) .

This co-development of Estidama as the methodology to transform Abu Dhabi into *a model of sustainable urbanization*, and the evolvement of Abu Dhabi building codes around sustainable elements introduced by Estidama resonates with the conceptualization of construction innovations as foundational and infrastructure for the development of built environment (Shibeika & Harty 2015). Furthermore, the innovation adoption decision for sustainable approaches in Abu Dhabi developments range from mandatory through the building codes or Pearl 1 rating for government buildings, to more voluntary adoption by achieving higher Pearl ratings, which call for further investigation of the adoption processes for both the mandatory and voluntary adoption of Estidama framework and whether there are any similarities and differences especially with regard to decision processes taken during the design and construction of new sustainable developments, or the role and influence of key team members such as the Pearl assessor who represent Estidama and the Pearl Qualified Professional who facilitates the assessment process and provides quality assurance for the rating application of developments.

PEARL rating system components as the communication channels for Estidama

The Pearl rating system is organized around seven categories: integrated development process, natural systems, livable buildings, precious water, resourceful energy, stewarding materials, and innovating practice. For each of these categories there are mandatory and optional credits, mandatory credits don't have points, while optional credits are assigned with points and the more points the development achieve from these optional credits the higher the rating it will achieve. These categories stand as communication channels to promote and diffuse sustainable development principles, as they provide design guidance and indicators for measuring the potential performance of developments.

The Pearl rating system also encourages the involvement of specific professional roles through the whole lifecycle of sustainable development projects; examples of these are involving qualified surveyors and cost engineers to provide whole lifecycle cost analysis of sustainability approaches, or environmental specialists to provide design and management strategy for natural systems. Besides promoting integration of multi-disciplinary teams for sustainable developments, the Pearl rating system enforce the adoption of important national and international standards as performance benchmarks; examples of these are some of CIBSE or Ashare standards beside local UAE standards.

Pearl system mobilize multiple communication channels for sustainable development, which flow in a two-way fashion, in one direction from Abu Dhabi UPC to sustainable developments in the form of design guidance and methods for measuring performance through standards and codes, and in the other direction from design and construction teams for sustainable developments to the UPC through providing multi-disciplinary and integrated evidence for sustainable design and construction strategies. The question is how these strategies actually are developed in practice. Moreover, different media is used to facilitate these communication channels such as: narratives, plans, photos, calculations, specifications, maps, etc. This turn the attention to the changing nature of communication channels from classic diffusion of innovations research, and pose questions for further investigations of the development of these channels through either top-down policy or bottom-up design and construction practice evidence.

Final discussion and next steps

This research is concerned with sustainable development of the built environment in the UAE, Estidama is the framework for sustainable development adopted by the UAE and the Pearl rating system is the assessment method developed to diffuse Estidama principles. While considering literature in building and construction innovation discussed above, adopting diffusion of innovations concepts as the analytical lens to explore the diffusion of sustainable development in Abu Dhabi requires great attention to the complex nature of design and construction work which is described as *complex web of contractual relationships* (Mike and Nick, 2001: p 339), and to the current and future role of environmental assessment methods such as Pearl as foundational and a *market transformation tool,* which not only provide objective evaluation of environmental performance but also enable green design guidance and encourage communication and integration within sustainable project teams (Cole 2005). Furthermore, the role of assessors and key sustainable design advocates and champions need to be considered as well as the effect of government policy and its discourse which emphasize *innovation regulatory framework, technology infrastructure, enabling services, and investment and incentives* as main parts of an innovation-enabling environment (Ministry of Cabinet Affairs 2015).

The next steps for this research is a pilot study to explore sustainable development policy and government discourse in relation to Estidama and Pearl, followed by an in-depth case studies of sustainable projects in the UAE which adopt Pearl rating system.

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Impact of Configuration Management on Safety: A Study in A Steel Manufacturing Industry

Themba Nkhuna, Innocent Musonda

[1]School of Civil Engineering and Built Environment, Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment
University of Johannesburg

Abstract

The paper reports on a study conducted to examine the impact of configuration management on safety in a steel manufacturing company. Findings from literature were used to determine the relationship between configuration management and safety. In addition to a review of literature, empirical data was collected from a steel manufacturing plant. This study adopted a qualitative research design approach in the form of case studies. These studies on specific events and interviews with professionals within the steel manufacturing organizations were carried out in order to achieve the objectives of the study. The initial stage involved identifying the problem, while the next stage entailed conducting a review of extant literature about the concept of CM, leading to a formulation of theories about its practice. Findings were that configuration management had a negative impact on safety in the steel manufacturing plant.

Keywords
Configuration management, Safety, steel manufacturing industry

1. Introduction

With rapid globalisation, a challenge to constantly adapt to change while providing consistent quality products to customers and managing competition is ever present (Yuchun et al., 2013; Phelan et al., 2014). Further challenges for organisations and manufacturing plants are the fact that their success is measured according to their ability to produce quality and consistent products in a safe effective way while satisfying customer needs. In the current environment, remaining competitive requires that organisations should focus more on the effectiveness of their operations (Guess, 2006). The effectiveness of business operations in delivery good quality products can however be hampered by safety incidents, reworks and lack of information. One way of improving effectiveness in business is through configuration management (CM) (Hastings, 2009). Configuration management is one of the systems used to manage project changes and track quality. Inadequate configuration management processes constitute a barrier in availing available good quality products that are safe and meet the specifications (Quigley et al., 2015). Lack of CM can also lead to loss of life or even of a facility as well as disappearance of information and failure to update drawings for every modification of the manufacturing plant or project, which could lead to loss of products, markets, customers, and sometimes, in loss of human life (Sorrentino, 2009; Parametric Technology Corporation, 2003; Quigley et al., 2015). Organisations are enabled to manage change and maintain quality and safety by implementing configuration management from the start (Wais, 2004). In the manufacturing industry, CM identifies controls, and maintains the consistency of manufacturing plant and the quality of manufactured products through the entire lifecycle of the product (Hodges, 2011). By so doing, it ensures the existence and the life of a product and thus configuration management is also used to enhance safety (Heruc et al., 2015). Therefore, research on the issue of configuration management is important.

1.1 Motivation of the study

The study was motivated by observations made by the researcher in a steel manufacturing plant. The observations were that unnecessary and preventable accidents could have been avoided had documentation of certain changes to equipment simply been recorded. The resulting loss of life was a compelling motivation to embark on the study. Equally, it was noted that implementation, or lack, of configuration management was attributed to a myriad of complex reasons. Therefore, given the consequences of what was perceived to be associated with configuration management and the complexity associated with its implementation, the current study was embarked upon. Therefore, from observations made by the researcher, it appears that there is little effort paid to configuration management in steel manufacturing plants in South Africa; this may result in a serious compromise of safety in the manufacturing plants during operation. The objective of the study was therefore to establish the extent to which configuration management impacts on occupational health and safety.

2. Literature Review

2.1 Brief history of the configuration management concept

The existence of CM dates back to the 1950s and the concept has been in use ever since (Otero et al., 2007; Admiari et al., 2010; Lindkvist et al., 2013). According to Lindkvist et al. (2013) and Steyn (2015), the United States (US) of America Department of Defense (DOD) (2001) adopted and documented the principles of CM when concerns were raised regarding aircraft design and maintenance. The US DOD's document (973 MLT-STD-973) became the 'encyclopaedia' of CM and to date continues to be the pillar for all the standards of configuration, as well as the EIA-649 standards.

Kidd et al. (2014) explained that CM was formally introduced by the US DOD in the 1950/60s where it was developed to address the lack of data uniformity and alter issues of control in the race for a successful missile launch in the 1950s. The history and origins of CM are further supported by Smith et al., (2015) indicating that CM has been practised since the 1970s by United States of America Department of Energy (DOE). Hass (2002) also expounds this, explaining that CM gained momentum in the late 1960s; by the late 1970s, military standards had been developed and published in this field. According to Otero et al. (2007) the use of CM continued to expand as the nuclear industry followed in the footsteps of US DOD (2011) by implementing CM to track equipment changes affecting operational safety during the 1980s. Concerning the above, Kääriäinen (2006) argues that the roots of this type of management are in the defence industry environment. One of the reasons why CM was introduced was to reduce the amount of rework that had become prevalent and was costing a great deal. It was also a way to manage parts in stock as well as parts that did not fit properly, thus managing quality (Kääriäinen, 2006).

Many sectors, including the software development industry, have adopted the use of CM to manage version control by tracking software modifications. According to Kidd et al., (2014) CM expanded in the 1990s and extended into other sectors of the industry where it helped with managing the lifecycle of the product. The nuclear power generation industry followed in the footsteps of other sectors, such as the military and software industry, by implementing CM to manage changes and keep records of changes in their plant equipment (Admiari et al., 2010). The International Standards Organization (ISO) adopted and implemented CM in 1994, perhaps bearing testimony to the criticality of the method (Kidd et al., 2014).

2.2 Definition of the configuration management

The International Atomic Energy Agency (IAEA), 2003; 2010) defined CM as the process whereby physical facilities and data of the facilities are managed and documented. Such records should include information on planning, design, changes, approvals, auditing and installation procedures. The US DOD (2001) defines CM as a process by means of which the design of a facility, its operating data and all the changes of the facility are well documented and there is consistency between documentation and physical facilities from the start to the end of the life of the facility or product lifecycle.

Configuration management is also viewed in terms of operation and documentation (Müller, 2013). Smith et al. (2015) define CM as the management process of facilities and their systems by their identity using documentation. According to ISO (2003) CM is like a map that provides direction of where the final product must end - as defined from the start - with the requirements and must ensure that the correct data is available and stored. In addition to merely documenting the systems and physical facilities that have been installed, Kääriäinen (2006) argues that CM, as a discipline, is that aspect of management which deals with the management of the modifications and the changes that take place during the lifecycle of the product under surveillance and strict management. It also entails strict monitoring of technical and administrative activities regarding physical installations is maintained by identifying, documenting, auditing and controlling changes through record keeping and reports (Kääriäinen, 2006) is in itself a discipline where strict monitoring of technical and administrative activities regarding physical installations is maintained by identifying, documenting, auditing and controlling changes through record keeping and reports. Monroy (2009) supports this definition and states that monitoring and controlling changes and storing the information about them, in turn results in facilities, products and documentation being in accord with each other. In other words, the physical appearance of an installation is exactly the same as the documentation about it.

2.3 Significance of configuration management

In a view of the need for effective and efficient maintenance, it is imperative to maintain and manage information and data as facilities age (IAEA 2003). Configuration management ensures that, as the facilities age, information is still in place and all the changes and modifications that were made over the years have been captured and documented (IAEA, 2010). This in turn ensures that major maintenance should be implemented without overwhelming setbacks as information is available and the migration or retirement of the workforce has been documented to assist the new workforce to continue and operate the facility safely, including undertaking maintenance, (IAEA, 2010). The European Cooperation for Space Standardization (2008) also highlights the importance of and the need for CM and contends that CM is a plan that is used to identify what is needed in terms of systems and resources and how the configuration should be carried out on the product, to manage and trace changes throughout the operating life or on the design. It ensures that the relationship between the as-designed, as-manufactured and the actual as-built configuration of the final product is maintained.

Where CM processes are clearly defined from the beginning - during the planning phase, the construction, operation and maintenance of the facilities as well as during the commissioning - the eventual product will meet the design specifications as per the plan and the associated requirements (Lindkvist et al., 2013). Configuration Management ensures the availability of accurate documentation and that information is in line with the physical structure and plant. This in turn ensures long term data archiving, robust and proven information, limiting of operators' costs, provision of safety for human operators, safe plant operations and safe maintenance of the facility (Hwang, 2013). As a result, decisions will be made with accurate information that can be relied on.

2.4 Impact of configuration management on safety

According to NASA (2011) safety is a freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to environment. The IAEA (2007) defines safety as the means for the protection of people and environment against harm. For many organisations, safety has become their number one priority. This is because neglecting safety may result in human fatalities, injuries and high costs for medical, insurance and penalties. In addition, accidents may result in loss of skills if there is a fatality or an injury, resulting in more than three days' absence from work. Business can also be shutdown resulting in loss of income (Kennedy, 1996).

Lack of CM has been cited to be a contributor to accidents and fatalities. An example is described in an investigation that was undertaken by Hastings (2009) into the collapse of the Interstate 35W bridge, resulting from the failure of gusset plates which were wrongly sized on the original design and ultimately led to 13 people losing their lives and a further 100 people being injured. It was found that adequate CM could have identified the incorrect thickness of the plates and the designs. In his findings, Hastings (2009) explained that the accident could not be faulted on construction or quality issues, but instead on the failure in CM, in so far as there was lack of information about the previous design and installation. In another example, three people lost their lives, with a number of injuries recorded, when a blast furnace exploded in UK Wales at the Corus Steel plant in 2001 (Curry, 2001). The findings on the cause of the explosion ranged from document control that affected maintenance quality to lack of updated documentation coupled with an aging plant.

Other studies supported that without auditing or verification was documented in terms of the changes that were not made or updating of standard operating procedures and drawings done and poor record-keeping of any changes, accidents can occur (Dhillon, 2002; Bierbrauer et al., 2013). Safety during maintenance stage of projects also depends on effectiveness of CM processes (Dhillon, 2002; IAEA, 2003). Effective maintenance procedures which can be undertaken in good time and safely, depend on known information about the physical configuration of the component or the section of a facility where maintenance has to be performed. Maintenance teams depend on accurate information from As-built drawings and the operating documentation to order spares and to do proper quality maintenance.

Ravi (2006) summarised the benefits of having a good CM in place as assisting teams to overcome operational problems, improving the archiving of information regarding plants, helping reduce costs, improving efficiency in reliability, availability and maintainability and complying with legal requirements.

3. Methods

3.1 Research design

This study adopted a qualitative research design approach in the form of case studies. using interviews, document search and observations. The case study methodology was adopted for the current study because, as elaborated by Rowley (2002) case studies are useful in providing answers to "how? And why?" type questions and therefore results can be used for a descriptive research, such as the current one. The case study entailed using a variety of evidence from sources, such as documents, artefacts, interviews and observation as suggested by Rowley (2002).

Interviews were conducted with professionals within the steel manufacturing organisations including engineers, project managers and draughts persons, on the implementation of CM and its impact on safety performance in the organization. The selection of respondents was based on their expertise, experience and the involvement in decision making in operations by the selected interviewees. Document analysis and observations were also used to study and gather information on specific events in the organization. The researcher collected the data by observing how projects and the operations were executed. Observations were also made through the observations of plant personnel during normal operating activities. The data collected during interviews, documentation and observations was then analysed using case studies from literature and comparisons were made to establish if there was a pattern in the failures and if CM had any hand in the failures.

Anonymity and voluntary participation were ensured before interviews commenced (Teddlie, 2009; Leedy et. al., 2014). Content analysis was used to analyse the collected data to establish the required result. Findings from one of the cases studies is presented here because it was directly related to safety performance.

4. Findings - Electrocution of the maintenance personnel

In this case, an electrician was electrocuted. Two electricians were requested to remove a broken crane. The electrician and his colleague responded to the call concerning a breakdown on the gantry. Isolations were carried out and the two electricians began with the maintenance of the gantry's electrical problems. As they were remedying the faults, both men were electrocuted and one died of his injuries.

According to the reports filed with the company and investigators, the two electricians first disconnected and secured the 500-volt electricity supply before they attempted to replace the damaged ends of the supply cables. After the electricians had undertaken this initial task, they noticed another breakdown: a ground connection of a busbar used to supply a 40-tonne auxiliary hoist stator circuit.

It was reported that before they could start any work on the 40 tonne auxiliary busbar, they had to make sure that the line was safe. Therefore, the electrician, who had the responsibility of isolating the line, communicated with his colleague, using a two way radio to warn him about the next operation. After warning his colleague, the first electrician (No.1) entered the crane cabin and disconnected the 230V supply voltage, so that they could establish the busbar's status; namely, whether it was energised or not. Shortly after the disconnection, the first electrician (No.1) heard a noise like a falling helmet. According to the reports, he, the first electrician, (No.1) on hearing the sound, stepped out from the cabin to check what could have happened. To his dismay, he saw his colleague, the second electrician (No.2) lying on the working platform which was used for maintenance of busbars. The reports indicate that the first electrician (No.1) immediately informed the head of the shift upon realising that his colleague had died.

Findings

In terms of the investigations conducted at the time, it was reported that the events that might have contributed to the fatality included the following:

- The power distribution of the crane had been modified a few days prior to the incident. After this modification, temporary lighting was installed on the crane; however, no one documented these alterations.
- The process for updating technical documentation on installations and informing the workers concerned after a temporary modification appeared to be ineffective; the results of the changes that took place led to the safety incident where a fatality was recorded.

Analysis of results

The electrocution of the maintenance men could be attributed to the following proximal factors as in figure 1. The gas plant failure, a newly constructed gas plant was merely able to operate for less than a year before a major overhaul was undertaken. Operations at the gas plant ceased after it experienced numerous outages and extensive maintenance requirements. These problems prompted management to shut down a newly constructed plant because there was clearly a problem.

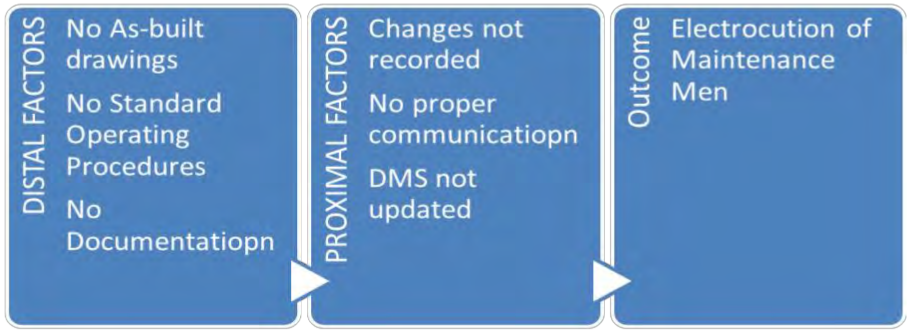

Figure 1: Constraint-restraint method detailing electrocution of maintenance personnel (Suraji et al., 2001)

Changes to equipment

Key findings from interviews revealed that lack of updating documentation, lack of training, cultural behaviour and deficiencies in implementation of CM may have been the factor in the failure of the gas plant. Feedback from engineers and plant people revealed that during construction of the gas plant changes that were made by procuring low cost equipment to replace more expensive equipment to save costs might have been the cause of the gas plant to fail. The changes have not been documented, there were no records indicating if there were changes recorded. The As-built drawings were not similar to what was installed in the gas plant as observed. Data was not found to suggest that the replacement equipment were tested to see if they met operating conditions.

Training was not provided to everyone involved in the gas plant. There was no documentation proving if training was done. The feedback that training was done was provided by top management and some of the operators verbally. A handful of operators were trained and were requested to train the rest of the plant of the gas plant operations. The operators or personnel trained have since left the gas plant.

From observations it looked like there is a culture of care free. The gas plant was operated and maintained without procedures and documentation. The observations highlighted a lack of discipline and fear, albeit the hazards and dangers that comes with the gas plant.

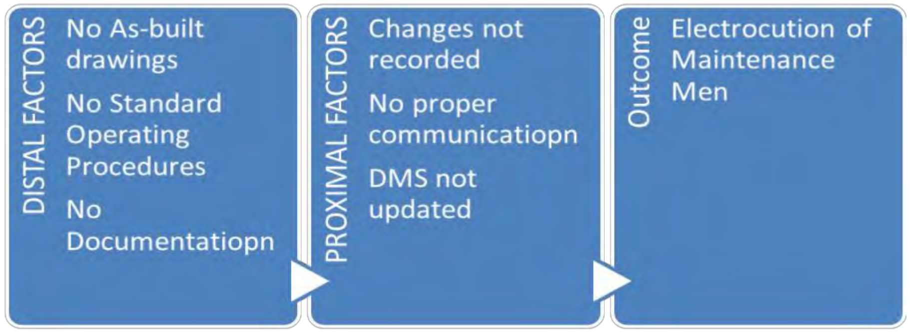

Figure 1: Constraint-restraint method detailing electrocution of maintenance personnel (Suraji et al., 2001)

Documentation from investigations and interviews revealed that changes to the power circuit were not recorded. There was no documentation or paper trail of what work was done by changing the power circuit. Communication was said to be lacking.

Interviews also revealed that the DMS system was not updated and there was no information on the request to do maintenance. The distal factors reveal that information suggest lack of proper communication, accountability and communication which is an aspect of CM. The Swiss model reveals that the factors and conditions all created a perfect environment and background for the fatality to occur. See figure 2 for schematic explanation.

5. Discussion - Impact of Configuration Management on Safety

In the fourth case reviewed in this study, the maintenance man died because no one had informed him or his colleague of modifications that had been made to the electricity supply; hence he proceeded to work, based on the assumptions that he was dealing with the original installation. Safety depends on the extent to which appropriate information is provided to the workers about a particular job, especially about dangerous jobs. Therefore, a lack of information could have been handy during the maintenance work.

According to the IAEA (2003), smooth operations and good maintenance are based on having a clear set of procedures in place as stipulated by the CM standards which allow for information to be in place when needed for maintenance or emergencies such as shutdowns, which in turn would assist with planning of maintenance and safe work procedures. This view is also supported by Jonathan, (2015); ETS, (2013) and Dhillon, (2002).

Safety is assured on a project if CM is done correctly, because as Hass (2010) puts it, CM is a summary that explains what is there, what must be there and what is actually there. Configuration Management implementation has a positive effect on safety performance.

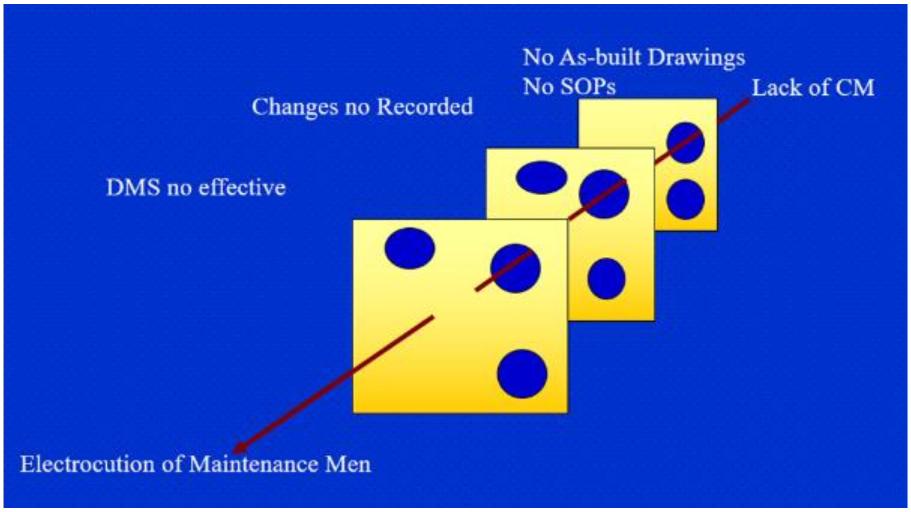

Figure 2: Swiss Cheese Model for the electrocution of maintenance man (Reason, 1998)

Conclusion and Limitations

Literature has demonstrated that CM has been in use for many years, its success has been proven in the nuclear industries, the military and many other high reliability industries (Admiari, 2010:25). Literature has also provided evidence that those who neglected it have paid a costly price with undesired results.

The current study also revealed that there was a relationship between CM and safety. The electrocution of the maintenance worker due to undocumented changes which were not communicated led to his death. Kääriäinen (2006:30) explains that CM ensures that changes are documented. In this case, changes were not recorded, leading to poor CM that ultimately resulted in an unwanted fatality.

Inadequate funding entailed that only what has been documented in the current study was achievable. Further, there is very little information from major industries in South Africa on CM and those that were engaged were not willing to share some information and this may have affected the results.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

Sustainability Indicators for a Transportation Infrastructure Investor

Chioma Okoro[3], Innocent Musonda[2], Justus Agumba[3]

[1,2,&3]School of Civil Engineering and Built Environment, Department of Construction Management and Quantity Surveying, Faculty of Engineering and the Built Environment

University of Johannesburg

chiomasokoro@gmail.com

Abstract

Sustainability of infrastructure has been a source of concern for ages. A panoply of literature exists on sustainability. However, few studies exist which focus on the sustainable outcomes which an infrastructure investor seeks when deciding to invest in a project. The current study reviews extant literature to identify factors which are indicative of sustainability, specifically to an investor. Transportation literature is focused on because of its economic nature and potentiality of returns to an investor. Studies in both international and South African context are included. Findings revealed that adequacy of funding, accessibility, safety and security, quality, reliability, environmental friendliness and strong institutions are desirable outcomes to an investor. These findings will assist in the development of strategies to ensure that infrastructure projects are financially and economically sustainable.

Keywords

Infrastructure, investment, investor, sustainability, transportation

1. Introduction

Infrastructures, in different forms including technological networks, transportation, and health care systems, are critical to the development and growth of any economy (Huang et al., 2014). Infrastructure development's impact on economic growth is significant as no economy can achieve high, sustained growth without the right infrastructure (Financial and Fiscal Commission (FFC), 2016; Department for Infrastructure Development (DFID), 2017). Transportation infrastructure in particular, provides for personal security, economic stability, public health and quality of life benefits (Pollalis, 2016). The failure of infrastructure may therefore be hazardous to the general population, the economy and even security (Huang et al., 2014). Thus, sustainability of infrastructure in terms of balanced costs and benefits as well as financial returns is desirable (Pollalis, 2016).

The sustainability of transport infrastructure projects in terms of leveraging maximum possible funding from the available sources while preserving and maintaining existing assets for future generations has been a focal attention for decades (Development Bank of Southern Africa (DBSA), 2012). Although sustainability of infrastructure has generally been regarded as the incorporation or realization of social, economic and environmental objectives in infrastructure development, other aspects of sustainability such as institutional and physical and importantly, financial sustainability are essential in transportation infrastructure development.

Given the long-term nature of transport infrastructure investments, financial sustainability is critical for investors (Hristova, 2015). The long economic life of infrastructure assets makes investors exposed to risks. Therefore, low risks and high certainty of periodic cash flow are primary considerations at the time of infrastructure planning (Blackrock, 2015). Investors typically seek long-term predictable yield-to-duration to match future liabilities/risks, costs and payments. Moreover, sustainability is a positive public good which must provide clear benefits and be financially obvious (Pollalis, 2016). Financial returns are particularly important in transportation infrastructure sustainability due to its economic nature and potential of revenue to an investor. Certainty or assurance about the stability of investments means less risk and decreases return requirements (Blackrock, 2015). Therefore, tools are needed to ensure that infrastructure projects are planned with the intent of attaining sustainability.

Studies on transportation infrastructure sustainability abound (Zou et al., 2011; Kaare and Koppel, 2012; Montgomery et al., 2015). However, most literature focus on the three-dimensional aspects (economic, social and environmental) (Litman, 2016). Although Haas et al. (2009) and Karlaftis and Kepaptsoglou (2012) acknowledged that infrastructure sustainability performance indicators may vary among stakeholders due to differing interests, they focused on road transport projects and included all stakeholders. Few studies have focused sustainability concerns of transportation infrastructure investors only. The current study therefore aims to fill this gap by identifying sustainability indicators which are important to an infrastructure investor to provide assurance of the worthwhileness of a proposed investment.

The objective of the current study is therefore to develop framework of sustainability indicators relevant to an investor in transportation infrastructure projects. Extant studies are reviewed, and the findings are presented in a matrix of sustainability indicators. The methods used to undertake the study are briefly described hereunder. The findings, and conclusions are presented thereafter.

2. Transportation Infrastructure Sustainability

2.1 Overview of the sustainability concept

The World Bank defines sustainability as the ability of a project to maintain an acceptable level of benefit flows through its economic life (Khan, 2000). It is the ability of a project to maintain its operations, services and benefits during its projected lifetime (Khan, ibid.). Transport infrastructure should be planned, designed, constructed, operated and maintained using best practices that sustainably integrates environmental, community and society, and economic attributes and promotes efficiency, safety, longevity, cost-effectiveness, community values and priorities (Ramani *et al.*, 2009; Montgomery *et al.*, 2015; Pollalis, 2016). The goal of sustainable transportation is to ensure that environmental, social and economic considerations are factored into decisions affecting transport activity (Corttrill and Derrible, 2015). Unsustainable activity is defined as “one which cannot continue to be carried on the way it is now without serious difficulties” and with regard to transportation infrastructure, this includes costs that transport systems pose to humans and the environment such as pollution (Oswald and McNeil, 2010).

There appears to be a general consensus on the need to achieve economic and social development and protect the environment, that is, the three basic dimensions (Zavrl and Zeren, 2010; Bueno *et al.*, 2015). However, the Commission on Sustainable Development of the United Nations (UNCSD) defined sustainability as having four dimensions, namely, economic, social, environmental and institutional (Brouwer and van Ittersum, 2010). Thus, institutional sustainability has been added as an indicator and this is especially important where multiple ministries, government departments and agencies at different levels of government are involved such as in the transportation infrastructure sector (Quium, 2014).

2. Indicators of infrastructure sustainability

Infrastructure sustainability can be measured using indicators or performance measures (Dhingra, 2011). Indicators are measures that provide specific information about the properties or attributes of a system (Cottrill and Derrible, 2015). Performance measures relate to how well a system is fulfilling or meeting its set of predicted goals and objectives and thus can be used in the case of transportation infrastructure sustainability measurement (Dhingra, 2011).

Sustainability indicators evidenced from rating systems such as CEEQUAL, LEED, Greenroads™, Envision ™, and so on, include environmental preservation, community impacts, health and safety, efficiency, financial sustainability, infrastructure resilience, economic development and land use, multi-modial transport, accessibility, affordability, travel demand, and pollution (CEEQUAL, 2007; Bueno *et al.*, 2015; Pollalis, 2016). However, most of the rating systems are usually regionally based and incorporate context-sensitive sustainability elements of the location where conceived (Bueno *et al.*, 2015). Thus, it is necessary to review and identify specific factors used to measure sustainability in related infrastructure sectors.

2.2.1 Sustainability indicators in the transport infrastructure sector

Sustainability of transportation infrastructure includes aspects related to accessibility, mobility, reliability, asset value, comfort and convenience, operational efficiency and effectiveness, positive public opinion/acceptability, travel experience, demand, safety, quality, improved socioeconomic conditions (boosting local productivity), integration of land use (balance) (Ramani et al., 2009; Henning et al., 2011; Montgomery et al., 2015; Litman, 2016; Barnes-Dabban et al., 2017; World Bank, 2017). Greenhouse emissions, congestion, accidents and pollution are also reflective of transport sustainability (United Nations (2015). The US Chamber of Commerce (2010) identified that supply, quality of service, safety, quality (structural deficiency) and utilization are criteria to measure transport sustainability performance. Likewise, Haas et al. (2009) found that safety, mobility and speed, reliability, environmental protection, productivity, user benefits, asset value, comfort and convenience, program delivery, operational efficiency were measures of road sustainability performance in international practice. Other studies included institutional sustainability as an important aspect (Jeon et al., 2010; Cottrill and Derrible, 2015; Barnes-Dabban et al., 2017).

Numerous factors have been identified as indicative of infrastructure sustainability. However, due to the economic nature of transport infrastructure, the relevant indicators are mainly economic and financial returns. Moreover, some indicators exist for different stakeholders as opined by Haas et al. (2009), Henning et al. (2011) and Karlaftis and Kepaptsoglou (2012). Therefore, selection of practicable and relevant factors relatable to transport infrastructure and for an investor is essential.

2.2.1.1 Investor-centered sustainability framework

An investment can be defined as having four elements, including a contribution of money; a certain duration; an element of risk; and a contribution to economic development (Grabowski, 2014). Thus, an investor, who could be either a natural person (individual) or legal persons (companies or businesses) (Nikièma, 2012), parts with money in the hopes of getting profits. Thus, more certainty about the stability of investments means less risk and decreases return requirements (Blackrock, 2015).

An investor's interest in and allocations to infrastructure are driven by a combination of factors such as low yields in traditional asset classes, potential link to other assets, stable cash flow/yield, and inflation protection and investment performance through the entire economic cycle (Mercer and Inter-American Development Bank (IDB), 2017). Infrastructure investors are interested in risk-adjusted returns as well as environmental and social outcomes (Mercer and IDB, 2016). There is an acknowledgement that strong due diligence inclusive of environmental, social and governance factors tends to reduce risk (Mercer and IDB, 2016).

Therefore, it is important to an investor, for instance, to recoup the capital injected into the project, in addition to conditions (including social and environmental and governance) which do not compromise returns as expected. This suggests that in the context of transport infrastructure investments, investors, who have alternative and sometimes conflicting ideas on projects to invest in, need to be confident about the decisions they make regarding the investment options they choose. Assurance of liquidity over a certain number of years is important since they should be in no doubt about the sustainability of the project. Transport infrastructure investors are interested in investments which guarantee risk-adjusted returns, inflation protection and/or match specific investment requirements as well as environmental and social outcomes (Mercer and IDB, 2016; 2017). This suggests that investors are interested in cash flow as well as favorable conditions (including quality) and frameworks (institutional) which guarantee sustained financial returns.

Consequently, a more rigorous synthesis of literature which focused on investors' interests was undertaken. It was found that although some factors are important in sustainability assessments, for instance, pollution and environmental protection, investors generally are not prepared to take lower returns on their capital to achieve the social and environmental impacts on the projects. The only exception is the case of impact investment, whereby investments are intended to create positive social impact beyond financial return (Jackson, 2013). Impact investment is made with specific and evident environmental and/or social returns, irrespective of the risks to financial sustainability, more especially in "impact first" investments (Hebb, 2013; Jackson, 2013). Therefore, it has been observed that transportation infrastructure investors typically invest with an aim to attain the following sustainability aspects including adequacy of funding, affordability, accessibility, safety and security, quality/standard of physical infrastructure, reliability, environmental friendliness/preservation and strong institutions. These are presented in the matrix in Table 1 and discussed further hereunder.

Adequacy of funding – This has to do with sufficient funds to cover the capital invested (cost recovery), expected cash income (financial reward) accruing to an investor as and when due, administration costs, and expenditure to maintain, expand, repair or replace capital infrastructure facilities to required standards, over the life cycle of the infrastructure (World Bank, 2013; Liyanage et al., 2015; IBNET, 2017).

Affordability – This has to do with ability to pay transport bills, taxes, tickets, and other charges (IBNET, 2017). Affordability is classified in some literature as a social factor (World Bank, 2013; Litman, 2016), and in others as an economic aspect of sustainability (Jeon et al., 2010). However, it can be argued that since it involves parting with money in order to fulfil a need, it is an economic aspect.

Accessibility – Accessibility is defined in terms of ease of getting to the transport facility from the most remote location within the catchment area (Henning et al., 2011). This has to do with fulfilling the basic need of access to and from destinations, by all citizens irrespective of income, location, or personal situation (Government of Sweden, 2016; World Bank, 2013; 2018).

Sa*fety and security* - Safety includes accidents risks such as accidents, fatalities, injuries and incidents (European Transport Safety Council (ETSC), 2016). It also includes existence of safety management programs (Karlaftis and Kepaptsoglou, 2012). Security data include crime statistics and perceived security from patrons (World Bank, 2013).

Quality/standard - This has to do with network performance in terms of quality or state of maintenance, breakdowns/potholes, frequency of maintenance (Karlaftis and Kepaptsoglou, 2012; IBNET, 2017). Good quality infrastructure leverages the optimum possible funding for an investor as people will be willing to pay for its use (Ramani et al., 2009).

Reliability - Reliability appeared to be the factor with the most consensus among the reviewed literature. Reliability is defined as the ability of fulfilling a function successfully. Reliability means that systems are in a condition to be able to accomplish a predetermined function during a prescribed period of service (Nagae and Wakabayashi, 2015). It includes aspects such as connectivity, capacity to bear demand, travel time savings, and resilience (Friedrich and Timol, 2011; GoS, 2016).

Environmental friendliness/preservation – This includes pollution levels, preservation of the natural landscape, efficacy of monitoring and evaluation and control policies (Ramani et al., 2009; (Karlaftis and Kepaptsoglou, 2012; World Bank, 2013; National Geographic, 2016).

Strong institutions - Institutional aspects cover various legal, governance, administrative, institutional, management and other non-technical aspects and arrangements, which serve as basis for decision-making (World Bank, 2013; Quium, 2014). These include legislation, management structure, resource allocation arrangements, project champions, clarity of responsibilities, incentive frameworks, efficiency of operations, and interaction among partners (World Bank, 2013; 2014; Upadhyaya et al., 2014; Cottrill and Derrible, 2015; Barnes-Dabban et al. 2017).

Table 1: Summary of key sustainability indicators

Author	Year of publication	Sustainability indicators							
		Adequate funding	Affordability	Accessibility	Safety & security	Quality/standard/ condition	Reliability	Environmental friendliness	Strong institutions
Haas et al.	2009				X		X	X	
Ramani et al.	2009			X	X	X	X	X	
Jeon et al.	2010		X		X		X	X	
Oswald & McNeil	2010		X	X	X		X	X	
US Chamber of Commerce	2010				X	X	X		
Henning et al.	2011	X		X			X		
Karlaftis and Kepaptsoglou	2012	X		X	X		X		
World Bank	2013	X	X	X	X		X		X

Upadhyaya et al.	2014	X				X	X		
World Bank	2014	X	X	X		X			X
Cottrill & Derrible	2015	X		X	X	X	X	X	X
DoT	2015					X	X		
Montgomery et al.	2015					X	X	X	
UN	2015	X			X			X	X
GoS	2016		X			X	X	X	
Litman	2016		X		X				
Mercer & IDB	2016	X							X
Barnes-Dabban et al.	2017						X	X	X
IBNET	2017	X	X	X		X	X		
World Bank	2017						X	X	
World Bank	2018	X	X	X	X			X	

3. Summary and Conclusion

The study sought to identify factors which are indicative of infrastructure sustainable performance from the view point of an investor who primarily seeks financial returns from the investment, albeit social and environmental and other economic factors cannot be overlooked. Thus, the objective of the study was met. The study found that an investor may be interested in risks adjusted returns and the conditions which can ultimately ensure that have to be in place to achieve sustainable performance of transportation infrastructure projects in terms of adequacy of funding, affordability, accessibility, safety and security, quality, reliability, environmental preservation, and strong institutions.

Continuity and security of funding for asset maintenance is crucial because without due attention to the physical infrastructure, the services and structures will eventually deteriorate. Poor quality infrastructure is detrimental to an investor as it results in low demand for services provided by the subject project. Monitoring and evaluation policies are critical to ensure risk-adjusted returns on infrastructure investments and environmental protection simultaneously. The effectiveness of institutions responsible for implementing such policies reflects sustainable performance. Efficacy of institutional frameworks helps in transparency and communication of information on long-term infrastructure pipelines and other potential projects and thus leading to proper estimation of infrastructure needs. Moreover, unfavorable regulatory frameworks pose risks to an investor and can have a depressing effect on infrastructure investment by increasing uncertainty in the eyes of investors.

Although the study is a literature review, these findings provide valuable evidence base for an investor to assess the worthwhileness of proposed projects during decision-making to invest. Further studies can employ primary research techniques to investigate the level of important of these factors among investors.

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Optimum Span Length for Steel Composite Girder Expressway Bridges

Hnin Su San
Asian Institute of Technology (AIT), Pathumthani, Thailand
E-mail: hninsusanpyae@gmail.com

Naveed Anwar
CEO/Executive Director AIT Solutions, Asian Institute of Technology (AIT)
Pathumthani, Thailand, Email: nanwar@ait.ac.th

Fawad Ahmed Najam
Assistant Professor, National University of Sciences and Technology (NUST)
Islamabad, Pakistan, Email: fawad@nice.nust.edu.pk

Abstract

This study presents the determination of optimum span length of steel composite girder bridges for expressways. Using a case study plate girder bridge, the cost curves for superstructure and substructure were developed for different span arrangements to find the most economical design case. The optimization is carried out for various parameters governing the girder design (web depth and balanced span arrangements). The case study bridge is designed for a span lengths ranging between 25 m and 50 m, and by varying the number of girders (3, 4 and 5 girders). The optimum spans in terms of economy are compared for two different shapes of girders (i.e. with constant depth of web and with tapered web). It is observed that tapering the girder web leads to 6%-10% reduction in weight of the girder while reducing the total cost of bridge by 8%-10% compared to the case corresponding to constant-depth web. Similarly, a significant reduction in overall cost can be achieved by reducing the number of girders in a cross-section using a similar optimization scheme. For the selected case study bridge, the three-girder case resulted in approximately 20% lower girder weight compared to four-girder case. The most economical span length is observed to be within 40m and 42m for three-girder system.

Keywords

Optimum span length, steel plate girder, tappered web, economical span, expressway bridges

1. Introduction

Plate girders are generally used for large spans and are constructed by riveting or welding the plates to an I-section. Since they are constructed using plates, they can be fabricated or tailor made to suit any design loads. This, in a way, offers greater freedom and convenience to the designer to choose from various sections of the plates available in the market. The optimal design of plate girders is governed by serviceability, flexural strength, shear strength and above all, the weight of the structure. The optimization of steel structures can thus be formulated as a weight minimization problem keeping in view the serviceability, flexural and shear strength aspects as suggested by the design codes. The plate girders comprise primarily of two flange plates and one web plate. The plates with different discrete thicknesses are available in the market. The designer is thus required to select the most appropriate size of the plates which will satisfy the design code provisions, while keeping the overall weight of the structure to minimum.

One of the effective techniques to achieve cost effectiveness and reduction in self-weight is the use of tapered (varying depth) web in plate girders (Limaye & Alandkar, 2013). Historically, the plate girders were fabricated by riveting or bolting, however nowadays it is possible to have welded plate girders. With welding, it is now possible to have various forms of web to construct tapered, cranked, and hunched girders. In order to achieve design optimization, web-tapered members can be shaped to provide the maximum strength and stiffness with the minimum weight.

This study aims to determine the optimum span of steel composite girder bridge for expressways in relation with minimum weight using AASHTO LRFD 2010 standard (AASHTO, 2010). Using a case study steel composite girder bridge, an economic comparison between different design cases (span lengths, constant/tapered web etc.) is conducted. The cost curves for both superstructure and substructure are developed for a series of preliminary designs and for different span arrangements. A parametric study is conducted by varying different design parameters to identify the case with minimum weight and with least cost.

2. Description of Case Study Bridge

A case study steel composite girder bridge is selected for detailed analysis, design and cost comparison. The section, 3D view and plan of the selected bridge are shown in Figure 1. It has two lanes with a total length of 1000 m (1 km) and a total width of 12.88 m. The thickness of deck slab is 250 mm. The bent cap is supported by two bent columns with a height of 9 m. The superstructure is supported by pile foundations (as shown in Figure 1) with a pile depth of 16 m. The average daily truck traffic ($ADTT_{SL}$) of 3000 is used for the design.

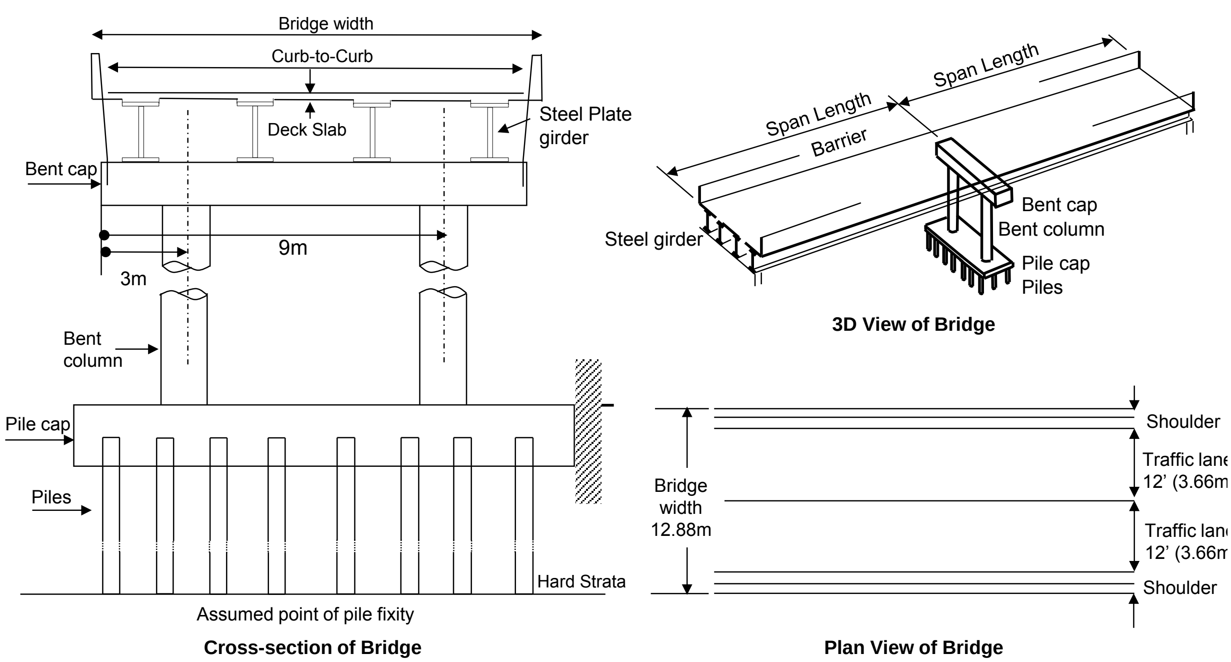


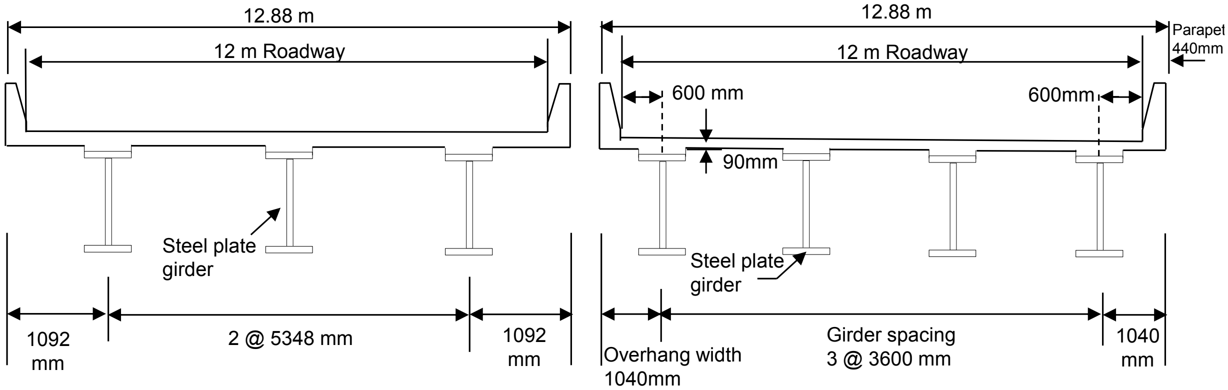
Figure 1: The section, 3D view and plan of the selected case study bridge

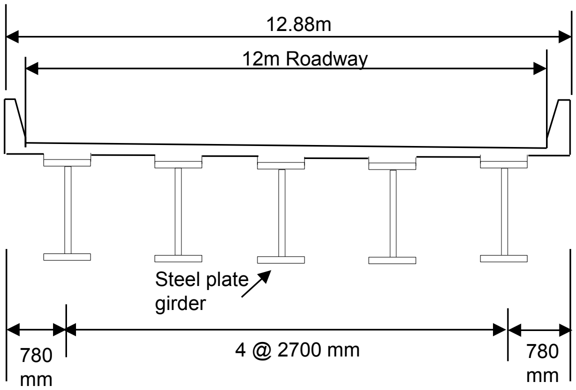
In this study, five different span lengths (i.e. 25 m, 30 m, 35 m, 40 m, 45 m and 50 m) of the case study bridge is considered. Similarly, the number of supporting girders is also varied to 3, 4 and 5, resulting in different design cases. For web design, the plate thicknesses of 13 mm, 14 mm, 15 mm, 16 mm, 17 mm and 18 mm are considered (AISC, 2010). For the design of web, the web depth may vary from 0.96 m to 1.90 m for Case 1 (constant web) while for Case 2 (tapered web), it can vary from 1 m to 1.8 m. The flange area is selected for each case as per the design requirement. The vertical intermediate stiffeners are also used in the design of girders. The design is carried out according to AASHTO LRFD design standard (AASHTO, 2010). No seismic and wind load effects are considered in the design.

3. Methodology and Design Procedure

The overall methodology can be described under the following steps.

a) Setting the span length (25 – 50 m with 5 m increment), number of girders (3, 4 and 5 girders) and the web type (Case 1: constant web, and Case 2: tapered web). Figure 2 shows the cross-section of bridge cases with 3, 4 and 5 girders.
b) Selecting a trial plate girder section
c) Separately analyzing and designing the superstructure of the bridge for each case. The design variables are the dimensions which determine the geometry of the optimized girders and control the overall cross-sectional area. These include,
    - Top flange width and thickness
    - Web height and thickness
    - Bottom flange width and thickness
d) Performing the cost estimation for superstructure for each case
e) Designing the substructure for each design case
f) Performing cost estimation for substructure and developing cost curves for both the superstructure and substructure for each case of span arrangement and web type
g) Identifying the optimum span for each design case. The point at which the superstructure cost curve intersects with the substructure cost curve is the optimum span of the bridge.





No of Girders	3	4	5
Girder Spacing (mm)	5348	3600	2700
Overhang length (mm)	1072	1040	780

Figure 2: The cross-section of case study bridge with 3, 4 and 5 number of supporting girders

The detailed three-dimensional finite element models were constructed for all combinations of cases and were analyzed (CSI, 2015). Figure 3 shows the FE models for both cases of web type considered in this study (i.e. constant web and tapered web). The bridge is assumed to be simply supported at the base of bent columns. The design calculations were carried out for all considered variables. Table 1 shows the range of variables considered for the design of steel girders.

Table 1: The range of variables for steel girders

Variable Elements	Geometric Constraints	Ranges (mm)	
		Case 1	Case 2
Flange Width (b_f)	$b_f \geq 12$" $b_f \geq D/5$ (Deep section) $b_f \geq D/6$(Shallow section)	305 – 432 mm	305- 495 mm
Flange Thickness (t_f)	$¾ \leq t_f \leq 4$	19 – 70 mm	19-38 mm
Web depth (d_w)	Straight $D \geq L/30$ $D/t_w \leq 150$ for web w/o longitudinal stiffeners	962-1923 mm	1000-1800 mm
Web Thickness (t_w)	½" (minimum)	13-18 mm	13-18 mm

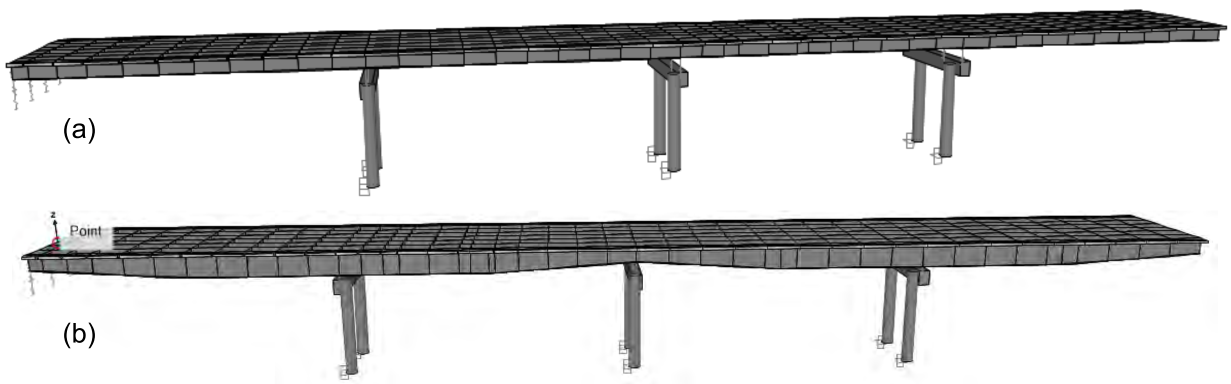


Figure 3: The 3D finite element models of the girder section with (a) uniform web, and (b) tapered web

After the design, the cost analysis was performed for each case by considering the unit cost of materials. The cost estimation was performed for each span and separately for both superstructure and substructure. The following three components of cost were included in the analysis in this study.

a) Basic cost of the material involved in construction/fabrication of the structure
b) Placement/ launching at the designated location of the structure
c) Finishing cost of the structure

4. Results and Discussion

Tables 2 and 3 show the design results in terms of final cross-sections of girders for all spans for Case 1 and 2, respectively. It can be seen that as the span length increases from 25 m to 50 m, the corresponding depths of girders increase from 962 mm to 1923 mm. The depth of a girder is often limited in industries due to headroom constraints and house service requirements. In this study, the girder depth is increased for six different span lengths and for different number of girders in order to evaluate the effect of changing web depths. The results reveal that the total weight of the girders is increasing constantly and gradually for a web depth ranged from 962 mm to 1923 mm. The result is predictable since it is reasonable to expect an increase in the depth of the plate girder, which would consequently increase the volume of the steel used and therefore a rise in the total steel weight.

Table 2: Cross-section of girders for different spans – Case 1

Plate Dimension Table												
			Variables (mm)									
No of girders	Span Length (m)	Width (mm)	Flange width (mm)	Top Flange Thickness (mm)			Bot Flange Thickness (mm)			Web height (mm)	Web thickness (mm)
				G1	G2	G3	G1	G2	G3		
3	25	12.88	305	19	38		22	41		962	13
	30	12.88	305	19	38		22	41		1300	14
	35	12.88	330	19	34	51	22	37	54	1500	15
	40	12.88	356	22	38	51	25	41	54	1539	16
	45	12.88	406	22	44	64	25	47	67	1731	17
	50	12.88	432	25	48	64	28	51	70	1923	18
4	25	12.88	305	19	38		22	41		926	13
	30	12.88	305	19	38		22	41		1118	14
	35	12.88	318	19	34	51	22	37	54	1296	15
	40	12.88	356	22	38	51	25	41	54	1482	16
	45	12.88	393	22	44	64	25	47	67	1667	17
	50	12.88	419	25	48	64	28	51	70	1852	18
5	25	12.88	305	19	38		22	41		893	13
	30	12.88	305	19	38		22	41		1072	14
	35	12.88	308	19	34	51	22	37	54	1250	15
	40	12.88	356	22	38	51	25	41	54	1429	16
	45	12.88	381	22	44	64	25	47	67	1607	17
	50	12.88	407	25	48	64	28	51	70	1786	18

The design of web design can also have a significant impact on the overall cost of a plate girder. From the standpoint of material costs, it is usually desirable to make girder webs as thin as design considerations will permit. However, this may not always result in the least cost solution since fabricating and installing stiffeners and shop operations may also affect the overall cost due to labor-intensive nature of work. Furthermore, as the web depth increases, it becomes more vulnerable to shear buckling. Consequently, it is necessary to increase the web thickness to satisfy the web buckling requirements. It can be seen that by increasing the span length, the depth of the web also increases in order to satisfy the upper limit constraint of the span-to-depth ratio. Moreover, the increase in the dimensions of both depth and width also requires a proportional increase in the thickness, resulting in an overall increase in the weight of the structure.

The optimum span arrangement can be determined by comparing the cost curves for superstructure, substructure and total structure for each span length considered in this study. It is obvious that the total weight of the steel girder increases proportionally with the span length. Similarly, with increase in the number of girder systems, the total required weight also increases, resulting in an increased total cost of superstructure. Figure 4 shows the overall cost comparison (per meter of both superstructure and substructure) for different span lengths of both cases (i.e. constant web and tapered web). The intersection point between the cost curves of superstructure and substructure is the optimal span length. It can be seen that by increasing the number of girders, the intersection point is shifted towards the higher span length. Table 4 shows the optimum span lengths for three-girder, four-girder and five-girder systems. The optimum span was found to be around 40 m with 3 girders at 5.34 m spacing. In 4-girder case, the optimum span lies between 40 m and 45 m with 3.6 m spacing. In 5-girder case, the optimum span was found to be within a range of 45 m to 50 m with a spacing of 2.7 m.

Table 3: Cross-section of girders for different spans – Case 2

Number of Girders	Web Height (mm)	Span Length (m)	Thickness of web (mm)	Flange Width (mm)	Flange Thickness (mm)
3	1 m at crown 1.8 m at support	25	13	305	19
		30	14	305	19
		35	15	330	22
		40	16	394	28
		45	17	438	32
		50	18	495	38
4	1 m at crown 1.8 m at support	25	13	305	19
		30	14	305	19
		35	15	330	22
		40	16	394	28
		45	17	438	32
		50	18	495	38
5	1 m at crown 1.6 m at support	25	13	305	19
		30	14	305	19
		35	15	330	22
		40	16	394	28
		45	17	438	32
		50	18	495	38

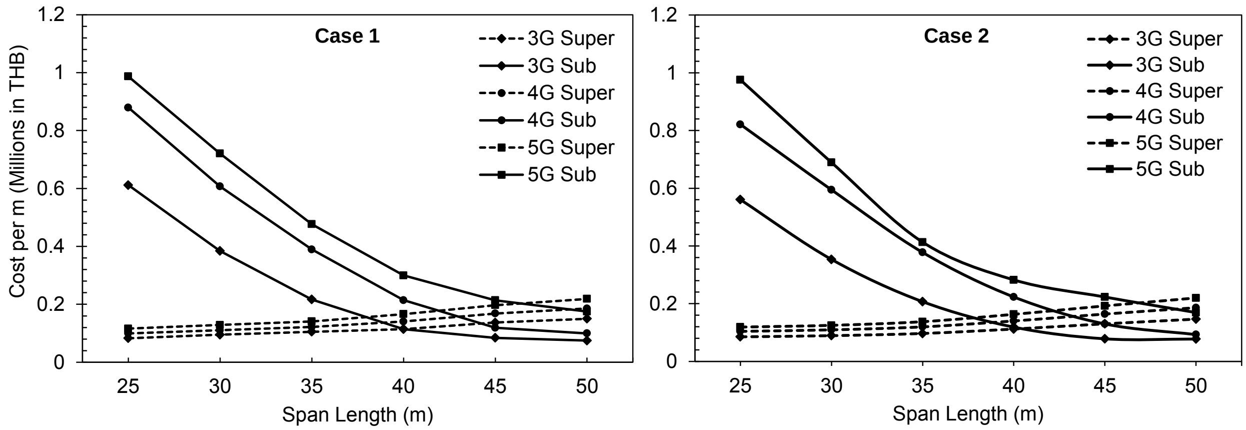


Figure 4: The overall cost comparison (for both superstructure and substructure) of both cases (i.e. constant web and tapered web)

Table 4: Optimum span lengths for three-girder, four-girder and five-girder systems

Girder Case	Optimal Span Length (m)
3G	40 – 42 m
4G	40 - 45 m
5G	45 – 50 m

Figure 5 shows the comparison (in terms of total weight and total cost) for three-girder, four-girder and five-girder systems at different span lengths. The result shows that Case 2 would result in a minimum of 6 % and a maximum of 10 % reduction in weight of plate girder compared to Case 1. It is also observed that an increase in the span length for each girder system will increase the total weight of steel girders by approximately 12 – 20% for Case 1. However, for case 2, this increase is approximately 6 – 19%. In terms of overall cost comparison shown in Figure 5, Case 2 is observed to be an economical solution. The total cost of bridge for Case 2 is around 8% - 10 % less than the total cost for Case 1.

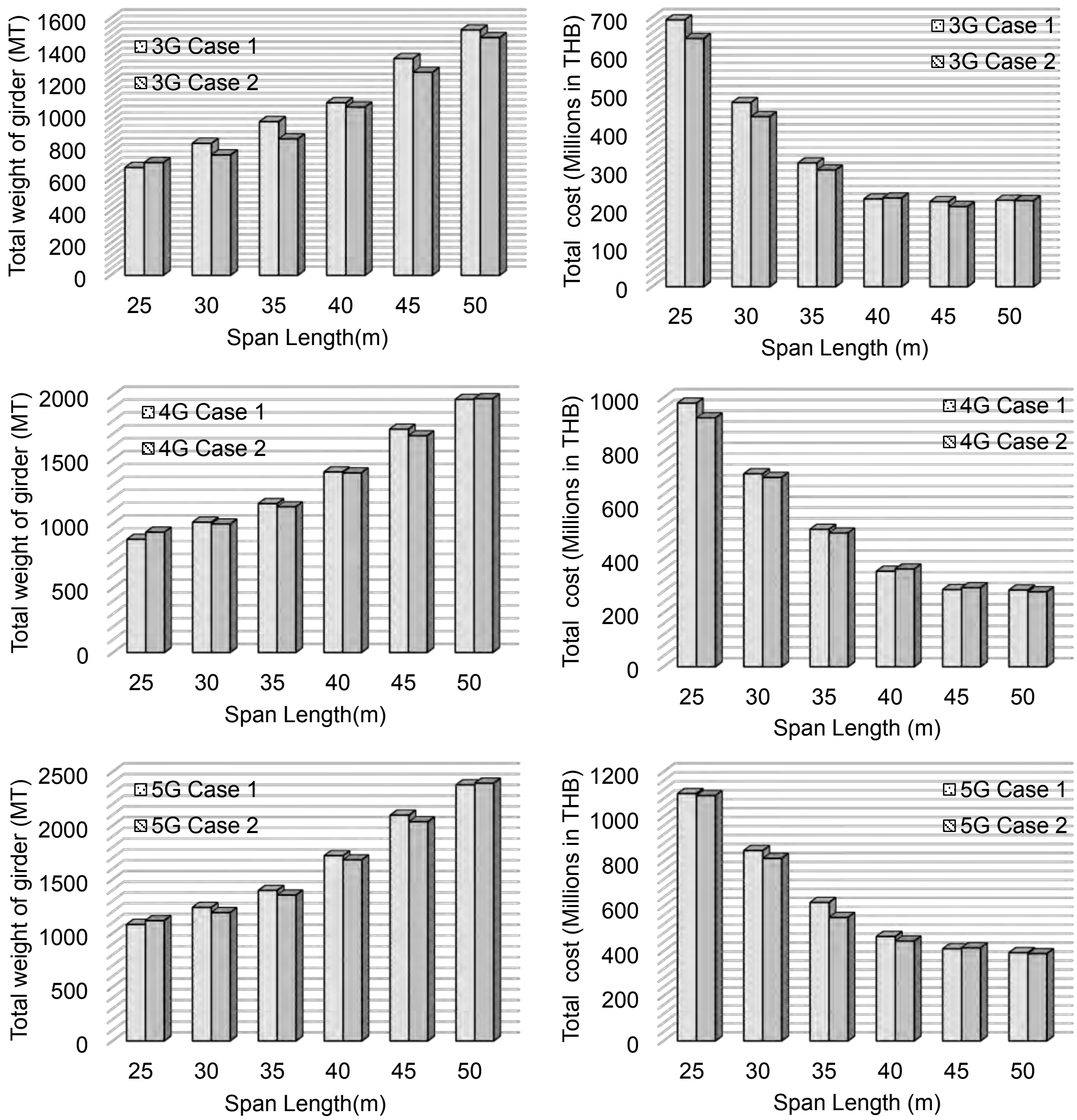


Figure 5: The comparison (in terms of total weight and total cost) for three-girder, four-girder and five-girder systems at different span lengths

5. Conclusions

In this study, several parameters affecting the cost of steel girder bridges are investigated including the variation of web depths, the thickness and width of flanges, the thickness of web and the effect of changing the span lengths. The results show that the use of tapered web leads to 6%-10% reduction in weight of the girder. The overall cost of case study bridge with tapered webs is observed to be 8% - 10% less than that with constant web. The 3-girder bridge case resulted in approximately 20% lower cross-sectional area compared to the 4-girder case which is again approximately 18% lower compared to 5-girder case. The optimal span range lies between 39 m and 41 m of 3-girder system for Case 1, while it ranges from 40 m to 42 m for Case 2.

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Construction Monitoring and Reporting using Drones and Unmanned Aerial Vehicles (UAVs)

Naveed Anwar
CEO/Executive Director AIT Solutions, Asian Institute of Technology (AIT)
Pathumthani, Thailand, Email: nanwar@ait.ac.th

Muhammad Amir Izhar
Senior Software Developer, AIT Solutions, Asian Institute of Technology (AIT)
Pathumthani, Thailand, Email: amirizharkhan@gmail.com

Fawad Ahmed Najam
Assistant professor, National University of Sciences and Technology (NUST)
Islamabad, Pakistan, Email: fawad@nice.nust.edu.pk

Abstract

The use of drones and Unmanned Aerial Vehicles (UAV) has been increased in recent years for surveying, facility management and other relevant fields. However, more recently, the technological progress in the design and navigation of low-weight and autonomous drones and UAVs have resulted in their more practical and cost-effective operation in the fields of architectural engineering and construction management and monitoring. This study presents a framework for the development of a fully automated smart construction monitoring and reporting system based on real-time data obtained from drones and UAVs. The data in terms of drone images from multiple locations and point clouds (from 3D scanning of construction site) can be used to construct a 3D model using the photogrammetry techniques. This so-called "drone model" can be compared to BIM model at various construction stages to monitor the construction progress. Beside construction scheduling and costing, this comparison can be expanded to include real-time recording, reporting, billing, verification and planning. Using the example of a case study construction project, the effective use of drone data is demonstrated in terms of smart construction monitoring and comparisons between drone model and BIM model. It is shown that this fully automated system can significantly reduce the effort required in traditional construction monitoring and reporting procedures. The system not only provides convenient and smart ways of site supervision and management but also results in better operations, planning and effective on-site adjustments.

Keywords

Smart construction monitoring, drones, unmanned aerial vehicles, smart reporting, photogrammetry

1. Introduction

With recent technological advancements, the use of drones and unmanned aerial vehicles (UAVs) is continuously increasing in various fields. Many industries are embracing the rapidly improving scientific tools and introducing smart solutions to solve real-world problems (ENR, 2015). The planning and monitoring of construction activities is one of the key areas where the drones and UAVs can significantly improve the performance and speed. In fact, the construction industry can take the advantage of such technologies in almost the whole range of practical aspects. For example, the drones and UAVs can be potentially used at several stages in a construction project including pre-planning, detailed survey and mapping of job site, construction process monitoring, post-build checks, and sales and marketing (Liu et al., 2014). Similarly, the drones can serve as a real time tool for the planners to monitor if their construction projects on the ground are conforming to their vision or not. The data acquired from drones can also help developers and construction firms to keep a track of their inventory and plan out the entire construction site.

This study presents a framework for the development of a fully automated smart construction monitoring and reporting system based on real-time data obtained from drones and UAVs. Figure 1 shows the key steps in traditional approach towards construction monitoring and planning. In conventional monitoring approach, the construction drawings are used to construct the BIM model which is then used to plan the construction sequence and monitor the progress. In the presented approach, the data in terms of drone and UAV images from multiple locations and point clouds (from 3D scanning of construction site) will be used to construct a 3D model using the photogrammetry technique. This so-called "drone model" can be compared to BIM model at various construction stages to monitor the construction progress. Figure 2 shows various stages of an example construction project demonstrated using a sequence of 3D models.

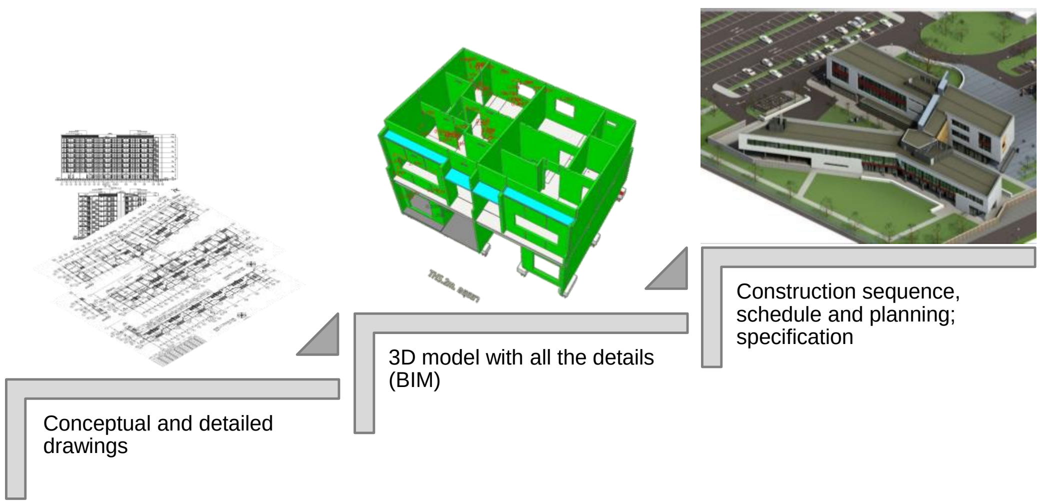


Figure 1: The key steps in traditional approach towards construction monitoring and planning

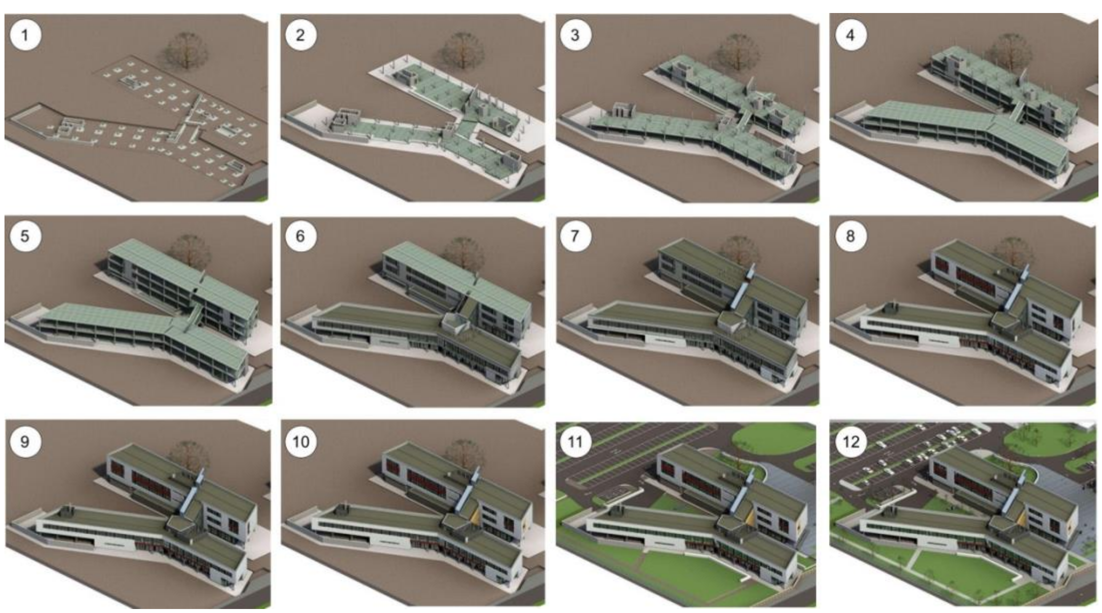


Figure 2: Various stages of a construction project as demonstrated by a sequence of 3D models

2. Smart Construction Monitoring using Drones and UAVs

The traditional approach for monitoring of construction projects involves a strict execution of plan without the possibility for any last minute changes. In this approach, the availability of accurate real-time data (showing the construction progress) is very limited. On the other hand, a smart monitoring system is based on organized real time data which is collected using various advanced tools e.g. drone- or UAV-mounted sensors (photo/video camera, thermal imaging camera and IR sensors etc.). The data is then analysed using advanced software which allow for better operations, planning and adjustments (Figure 3). Some of the important applications of drones and UAVs in construction monitoring include the following.

a) *3D Map Creation:* Aerial monitoring provides data for 3D object creation and area's orthophotographic map. The data can be continuously updated and stored as an online map for interactive viewing of objects. This provides a better control over the work progress and the ability to provide investors and clients with the most recent visual information. This also equips and provides the ease to the government agencies to detect illegal construction detection.

b) *Aerial Photography & 3D Scanning of Construction Projects:* Aerial photo and video can be used to provide clients with impressive visuals such as the view out the future window at the earliest stages of construction. A 3D model of a construction project makes every fine detail available for viewing online. The model can also be used in further planning, including that of landscaping and interior design

c) *Routing Construction Progress Monitoring:* Throughout a development's construction phase (and even before), agreed flight paths over and around the site can be made to provide almost real time visual progress reporting for developers, stakeholders and even the people on site as an engaging record of how the project is going. Either monthly or fortnightly visits with a number of ad-hoc visits throughout the development to capture key milestones.

d) *Volumetric Measurement:* Using accurate aerial photogrammetry techniques, large areas (2D and 3D) can be measured to within accuracy in centimetres. This can be accomplished quickly, cost effectively and with minimal disruption to the day to day workings of the site.

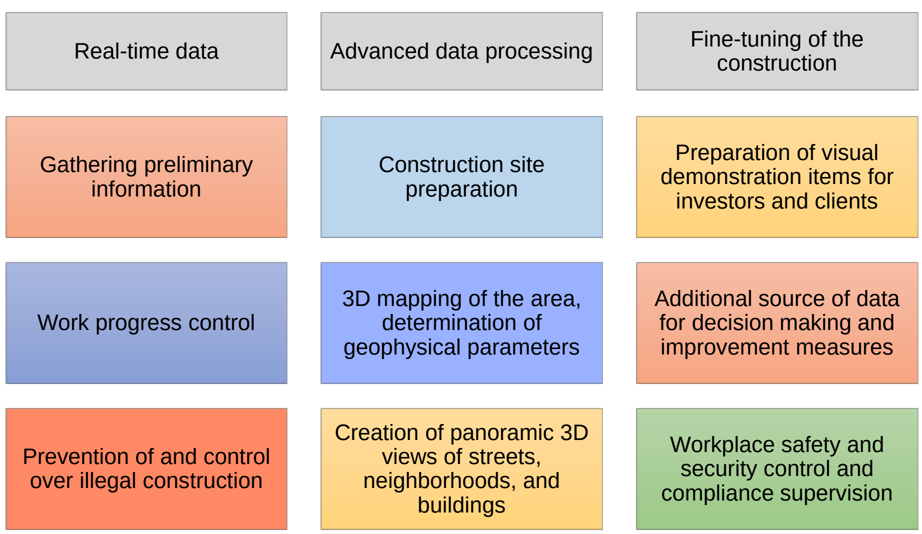


Figure 3: The key elements of smart construction monitoring system using drones and UAVs

Figure 4 shows the proposed framework of construction monitoring/reporting using drones and unmanned aerial vehicles (UAV). The high-resolution images and videos can be obtained with weekly, bi-weekly or monthly site visits allowing the engineers "to be always on site". Using UAVs, what used to take weeks can be done in days now. Even before the start of construction activity, the drone images and videos can be used to perform an efficient work space planning and optimization to reduce material flow bottlenecks as well as the periodic inspection for assessing safety measures in place. These reports such as the amount of material moved, excavated and filled along with tracking and monitoring of assets over the course of the project provide a viable and scalable method of knowing what is happening on the field for all stakeholders concerned.

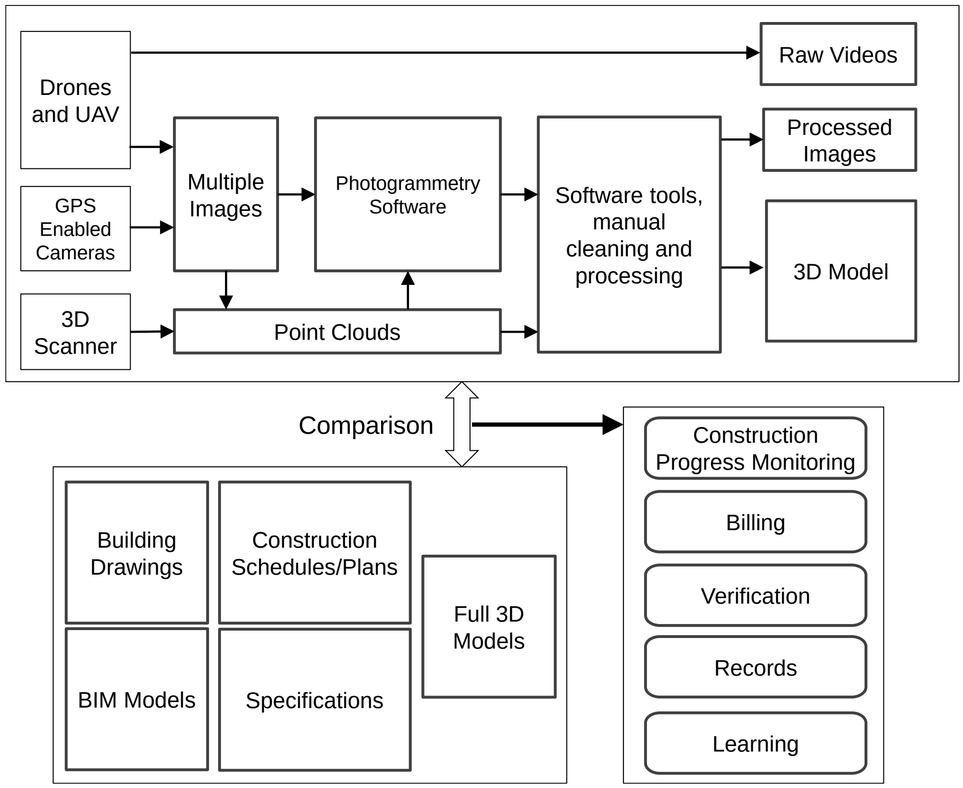


Figure 4: The overall concept of construction monitoring/reporting using drones and unmanned aerial vehicles (UAV)

The data obtained from drones and UAVs can then be analysed using various software to extract useful information for decision-making. The analysis of data has remained an interesting subject of research for more than a decade (Ham et al., 2016). In recent years, several image processing, computer vision, and geometrical processing techniques are developed which can either generate semantically-rich 3D models from the collections of overlapping images, or can be used to manually or semi-automatically conduct progress monitoring, surveying, safety inspection, quality monitoring and activity analysis during the construction. Several of the presented techniques can be used to streamline the condition assessment in existing buildings and infrastructure systems. A comprehensive review of these techniques can be seem in Cho et al. (2015), Son et al. (2015), Teizer (2015) and Yang et al. (2015).

Figure 5 shows the basic idea of converting the drone data into 3D model which can be routinely used to monitor the construction process over the course of project. The process of creating 3D model of an object from the images is called 3D reconstruction. This process captures the 3D shape and appearance of real objects. Several available software are capable of automatically extracting thousands of common points between images. Each characteristic point found in an image is called a key point. When two keypoints on two different images are found to be the same, they are matched key points. Similarly, each group of correctly matched key points generates one 3D point. When there is high overlap between two images, the common area captured is larger and therefore, more key points can be matched together. The larger the number of key points, the greater is the accuracy of 3D reconstruction. Therefore, it is very important to maintain a high overlap between the images. To create a 3D model of a flat surface, generally, nadir imagery is enough. However, to construct a 3D model of a structure e.g. an under-construction building, the overhead images are not capable enough to capture the details on sides of the building. For this reason, orbital flights around the structure capturing oblique imagery are recommended to improve the quality of 3D model.

The 3D drone model can then be used to provide important information about the construction process and can serve as a valuable tool for managerial decision-making or cost control. For example, it is very important to monitor the amount of material entering and leaving the construction site. The volumetric comparison between the BIM model and the drone models can be carried out at various stages of the project to track the amount of material. The drone data can also be used to assess the quality of concrete pours and accuracy in dimensions of structural members.

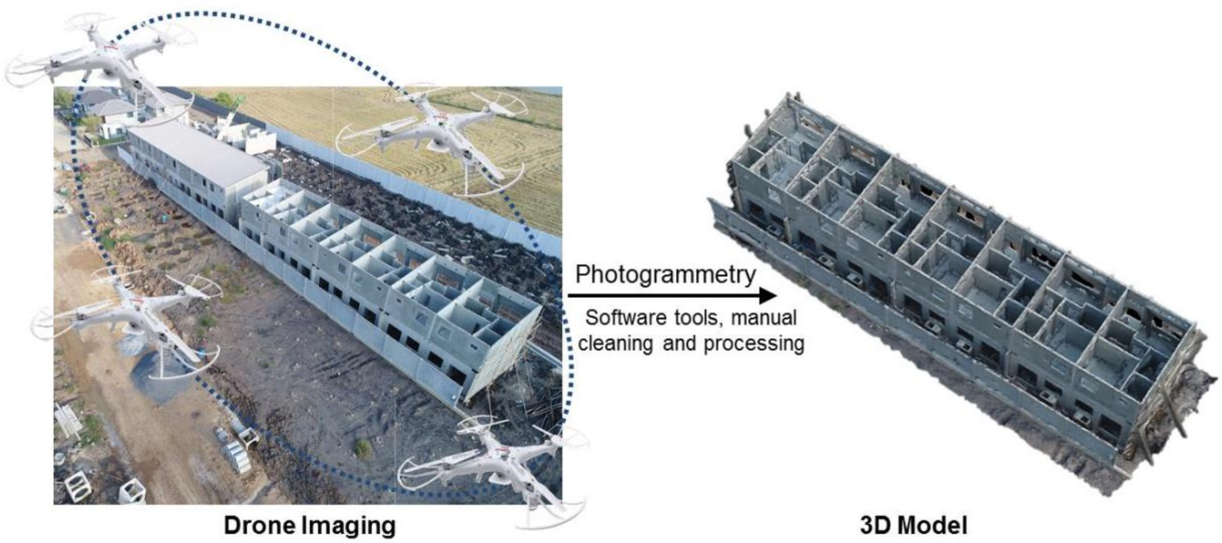


Figure 5: The conversion of drone data into 3D model

Beside construction scheduling and costing, this comparison can be expanded to include real-time recording, reporting, billing, verification and planning. Using the example of a case study construction project, the effective use of drone data is demonstrated in terms of smart construction monitoring and comparisons between drone model and BIM model. It is shown that this fully automated system can significantly reduce the effort required in traditional construction monitoring and reporting procedures. The system not only provides convenient and smart ways of site supervision and management but also results in better operations, planning and effective on-site adjustments.

3. Monitoring of a Case Study Project using Drones

The presented approach of smart construction monitoring is applied to a case study construction project of a single-story residential apartments building. The construction activities were continuously monitored using drones. At several stages of construction, the drone is flown a minimum of four times to capture various data with different height and camera angle settings. For the first data set, images are acquired with camera angle at 0 degree with a height of approximately 30 meters above the case study building height. The second data set is obtained by flying the drone at of approximately 20 meters from building height with the camera angle of 80 degrees. For the third data set, drone is flown again at a height of 30 meters from building height with an angle of 45 degree. The final data set is obtained by flying the drone at a height of approximately 50 meters at an angle of 30 degrees.

After the completion of aerial photography, the collected data was analyzed to construct the 3D models. A software named "3DF Zephyr" is used for 3D reconstruction. Once the 3D model is generated, it is exported in .obj (Wavefront) format. This data is then imported into REVIT and overlaid with the actual REVIT models to compare different dimension of the buildings. Using this overlay, a variety of comparisons at different stages of construction project were carried out. Figure 6 shows the potential results obtained from the presented drone-based construction monitoring approach.

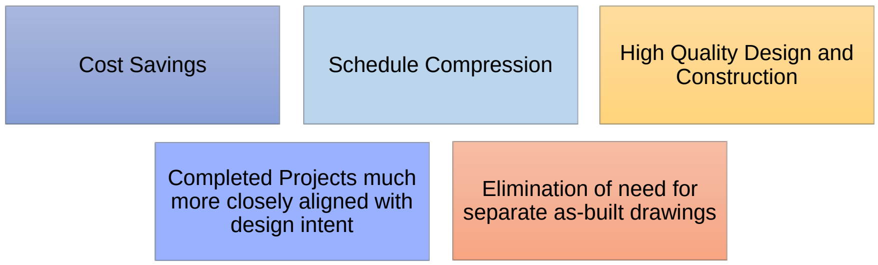
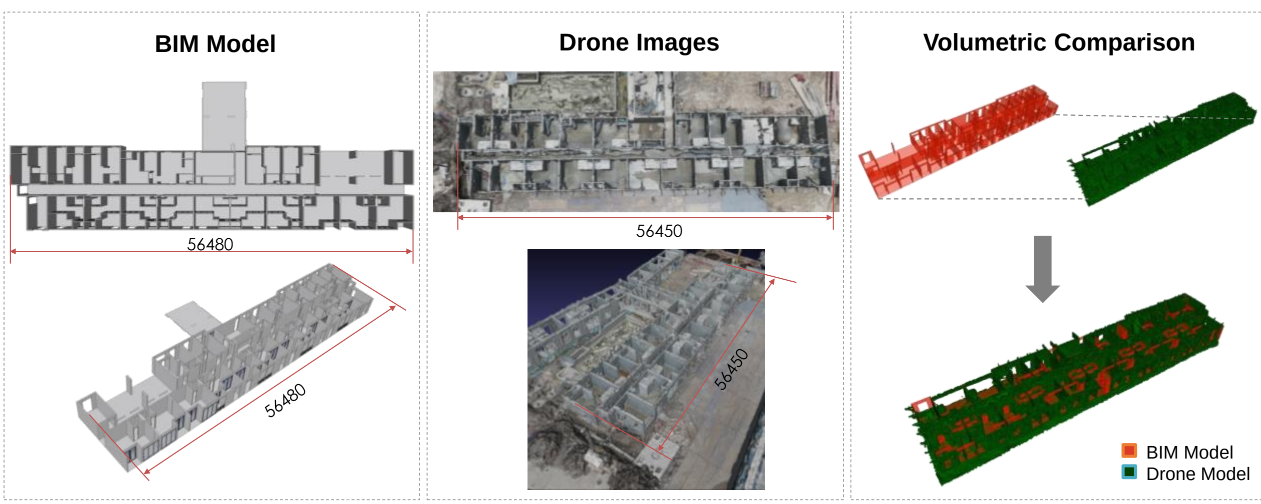


Figure 6: The potential range of results obtained from the drone-based construction monitoring approach

Figure 7 presents the volumetric comparison between construction plan/schedule and on-site progress for the selected case study project. The comparison between the BIM model (red colour) and drone model (green colour) shows the project progress. Various benchmarks and targets can be set and the project can be routinely monitored with a reasonable accuracy. Similar comparisons can also be made at various stages of the project. As an example, Figure 8 shows an example quantity comparison for the placement of toilets. The comparison shows that all toilets are on schedule. Similarly Figure 9 shows an example schedule comparison for the placement of windows in the case study project. The comparison shows that the placement is delayed by schedule. This case study application reflects the effectiveness of presented approach for smart monitoring of construction projects.



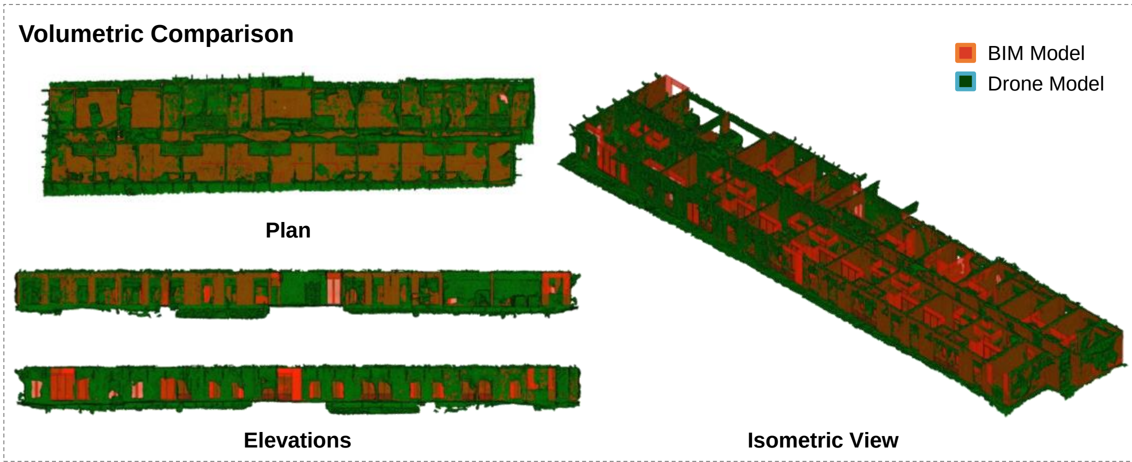


Figure 7: The volumetric comparison between construction plan/schedule and on-site progress

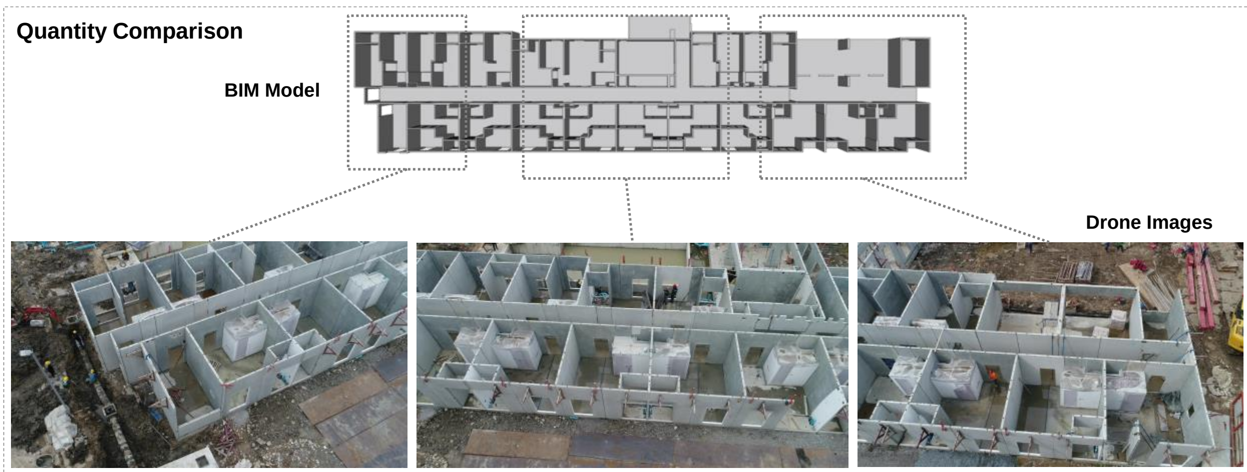


Figure 8: An example quantity comparison for the placement of toilets – All toilets are on schedule

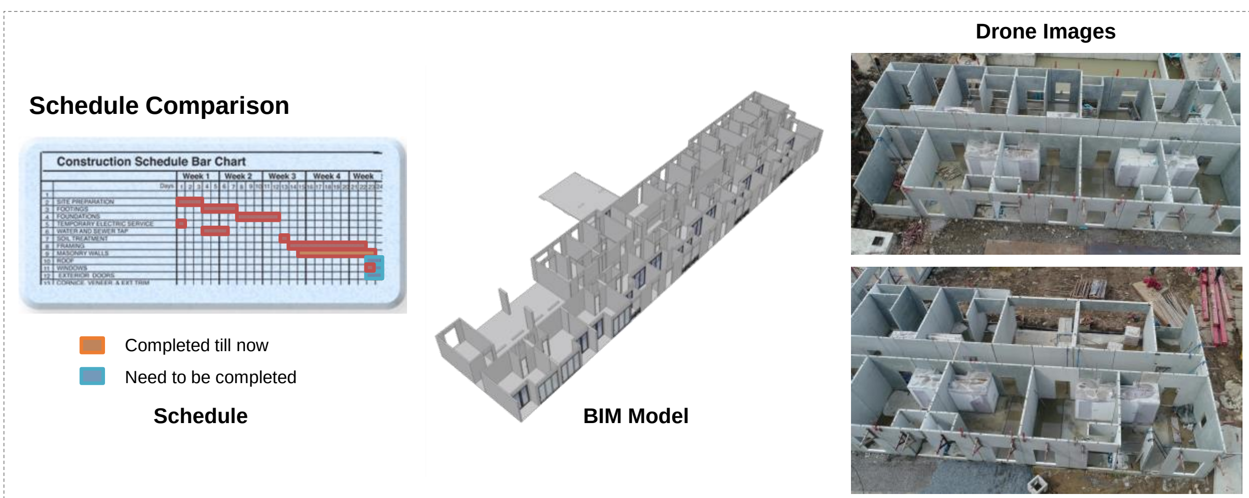


Figure 9: An example schedule comparison for the case study project – The placement of windows is delayed by schedule

For assessing the accuracy of presented technique, it is applied to five other case study buildings and the results were compared with actual data. The dimensions of case study buildings were measured and then compared with the 3D drone models. It is observed that the drone 3D models are reasonably consistent in shape and geometry of the actual buildings. However, in some cases, there can be certain types of errors due to data source, quality of data, the height of the drone, the angle of the camera while capturing the images and the construction methods. The mean error in the control point measurements for five tested cases was found to be less than 0.12 meters.

4. Conclusions

This paper presents the framework for the development of a fully automated smart construction monitoring and reporting system based on real-time data obtained from drones and UAVs. The technological progress in the design and navigation of low-weight and autonomous drones and UAVs can be efficiently used in a dynamic manner to result in a more practical and cost-effective operations in the fields of construction management and monitoring. In the presented approach, the data in terms of drone images from multiple locations and point clouds (from 3D scanning of construction site) can be used to construct 3D models using the photogrammetry techniques. These drone models can be compared to BIM model at various construction stages to monitor the construction progress. Beside construction scheduling and costing, this comparison can be expanded to include real-time recording, reporting, billing, verification and planning. Using the example of a case study construction project, the effective use of drone data is demonstrated in terms of smart construction monitoring and comparisons between drone model and BIM model. It is shown that this fully automated system can significantly reduce the effort required in traditional construction monitoring and reporting procedures. The system not only provides convenient and smart ways of site supervision and management but also results in better operations, planning and effective on-site adjustments.

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Occupational Stress and the Project Manager

Ken Farnes
RMIT University, Melbourne, Victoria, Australia
kenneth.farnes@rmit.edu.au

Abstract

There has been a dramatic growth in the business importance and economic contribution of project work across the economy. Despite advances in project management practices and the profession, projects continue to have an unacceptably high failure rate which is compounded by project managers being highly stressed, due to time pressures, project uncertainties, and the complex and often dynamic social structure involved in the project environment.

This study observed that when discussing the person-environment fit and competencies of a project manager, occupational stress and stress management were overlooked by the executive project sponsors as a possible contributing factor for poor project manager performance and poor project outcomes.

Despite the growing body of research evidence that has identified occupational stress across many different professions as having an adverse impact on an individual's performance and health, there has been little recognition within the project management literature of the impacts of stress or coping strategies for managing stressors within the project environment. This strongly suggests that additional research on stress focused on the project environment is warranted and that both project sponsors and project managers need to be made aware of the antecedents to stress and the consequences of stress both in the personal and business sense.

Keywords

Occupational stress, Workplace stress, Project Manager, Job performance, Decision making

1. Introduction

Stress in the workplace is of growing concern for employers and employees. Workplace (occupational) stress can impact an organisation's productivity through absenteeism and poor employee productivity and can negatively impact an individual's mood states and health. Occupational stress can be viewed as the individuals' reactions to the characteristics of the workplace which appear threatening (Kahn et al., 1964). It points to a poor "person-environment" fit, that is the fit between an individuals' capabilities, competencies, and the workplace environment, in which either excessive demands are made upon the individual, or the individual is not fully equipped to handle a particular work situation with the "misfit" between the individual and the environment being the basis for an individual's adverse behavioral and psychological reactions (French, 1963, Bussing and Glaser, 1999).

Since the early 1970s there has been a growing body of evidence in the form of laboratory and workplace studies (Kach & Quinn, 1970; Margolis et al, 1974 – cited (Cooper and Marshall, 2013)) that have identified occupational stress factors as having an adverse impact on an individual's health and job performance. Occupational stress is directly related to sickness, absenteeism, and workplace injuries. In 2017 the average number of days of absenteeism per employee in Australia was 9.7 days per year. The total loss in payroll and lost productivity in 2017 was approximately AUD$30 Billion (DHS, 2017).

Stress is unavoidable in life and can be either positive or negative depending upon how an individual perceives it. Their reaction to, and capacity to cope with stress depends upon their personality and their perception of the stressors. Project management, as with all occupations, has a certain amount of workplace stress associated with it. Stress is an outcome of change and conflict, both of which are inevitable in the project environment, but a certain level of stress is sometimes necessary to improve project performance. Consequently, stress is a necessary part of project life, and an understanding of stress and stress management must be considered as important elements of project management.

While all occupations have a certain degree of stress associated with them, the project manager can experience a significant level of stress because of an endless list of demands, deadlines, and problems occurring throughout the project life cycle. Project managers must learn how to cope with and effectively manage stress to avoid headaches, ulcers, anxiety, or many other stress-related ailments which may contribute to poor performance and the subsequent negative impacts on the project. For effective stress management, they must understand what stress is, how and why it is created, and how stress can be managed.

Based upon empirical studies, organisational behavioural scientists and practitioners have suggested that stress is linked to an individual's physical and mental health (Cobb, 1976, Morris and Snyder, 1979) to coronary heart disease (House, 1974, Matteson and Ivancevich, 1979); to absenteeism (Margolis et al., 1974, Gupta and Beehr, 1979); to staff turnover (Porter et al., 1974, Gupta and Beehr, 1979); and to job dissatisfaction (Lyons, 1971, Miles, 1975, Beehr, 1976).

The executives (project sponsors) who are managing the project managers must also be aware of the stressors placed upon a project manager during the project, they must be alert to the potential impacts on the project manager's performance, their physical and mental health, and also to the consequential impacts on the project.

1.1. Research context

This research is a part of a doctoral study being completed in the School of Property, Construction and Project Management at RMIT University which is centered on the person-environment fit attributes of a project manager. The objective of this study is to provide greater clarification of the person-fit attributes that contribute to improving project success, to assist employers, recruiters, and senior management to better understand the attributes of a project manager that best suits a particular project, and to explore whether organisations recognise the value of person-environment fit as project success criteria.

1.2. Method

The ever-increasing reliance on the project manager within Australian organisations to deliver new products, services, and implement strategic initiatives has attracted the attention of researchers interested in the human element of project management.

This research explores the project manager from the perspective of executive and senior management. It is qualitative in nature and based on postmodern social constructionist / interpretivist philosophy founded in the study of human based systems (Gergen, 1978, Gergen, 2009, Lewis et al., 2008). The research is premised on Appreciative Inquiry which is a form of participatory management and is typically seen as an approach that may drive positive personal or organisational change (Whitney and Trosten-Bloom, 2003).

The author interviewed thirty-six participants who act as project sponsors for projects of significance within their respective organisations. The executive and senior management participants were selected through a purposive sampling approach (Miles et al., 2013) to ensure that the selected interview participants came from a broad range of industries. Purposive sampling is a technique that enables the researcher to identify potential participants from a large parent population by virtue of their knowledge, experience, organisational position, and other significant attributes. Purposive sampling is used when the selected participants sample is fundamental to the quality of the data. This was done to reduce the opportunity of being locked into a particular context or ‘reality’, to enhance the opportunity to ‘generalise’ the study outcomes to other situations, to improve the ‘trustworthiness’ (Lincoln and Guba, 1985, Saldaña, 2015) of the data, to ensure that the key constituencies are covered, and to ensure that there is diversity across a variety of industry sectors.

A semi-structured interview process was deemed to be the most appropriate means of obtaining a detailed account of the participant’s experiences as it would allow the participant the freedom to describe their experiences. The interviews followed a narrative style, which may be regarded as a conversational partnership between the researcher and the individual participant.

2. Literature review

Workers commonly complain about occupational stress (Taylor et al., 2004). Research into stress began in the 1930s with Dr. Hans Selye when he postulated that stress is a non-specific response of human body to any demand on it (Selye, 1959, Selye, 1976, Selye, 1993). This view is supported by recent research that postulates stress occurs whenever a demand exceeds the regulatory capacity of an organism, particularly in situations that are unpredictable and uncontrollable (Dickerson and Kemeny, 2004).

The project environment can often be unpredictable and uncontrollable. Project managers are generally considered to be a key resource in the successful delivery of a project and are required to manage, plan, organise, and control complex and complicated projects involving demanding tasks, tight deadlines, changes to the project scope, multiple stakeholders who often have divergent expectations, and frequently work in adverse physical environments. This results in many decisions being made under stressful conditions. The decision making of an individual who works under stressful situations is generally more rigid, simplistic, and superficial (Friend, 1982, Cherrington, 1994) and research has shown that decisions made under stressful conditions tend to be less well-thought out and much more irrational (Keinan et al., 1987, Lazarus, 2000, Starcke et al., 2008, Galvan and Rahdar, 2013) thus indicating that stress has a negative impact on an individual’s performance.

In contrast to the few studies showing positive effects associated with stress, there are a great many that have revealed that stress affects decision-making in a negative way (Staal, 2004). Research on decision making under stressful conditions demonstrates that an individual under stress will not fully consider the situation and all of the possible options, tending to make decisions in a rushed and unsystematic manner (Janis and Mann, 1977, Mather and Lighthall, 2012, Galvan and Rahdar, 2013) leading to a number of undesirable consequences, including a restriction or narrowing of attention, increased distraction, increases in reaction time, and deficits in the individual’s working memory (Driskell et al., 1999) and a tendency to develop poor interpersonal relationships (Leung et al., 2005).

Since every single project decision made by the project manager has a direct impact on the time, cost, scope, and quality of a project’s outcome, it is inevitable that the project manager is subjected to a great deal of occupational stress. Researchers have investigated the impacts of stress on the performance of a variety of groups including: managers (Joiner, 2001), police officers (Tang and Hammontree, 1992, Collins and Gibbs, 2003), students (Wolk and Bloom, 1978), nurses (Dailey et al., 1986), teachers (Byosiere, 1987, De Heus and Diekstra, 1999), and human service workers (Wieclaw et al., 2006).
Project management literature is de-personalised and mostly focuses on processes and prescriptions, consequently investigations into the impact of stress on the performance of project managers is sadly lacking, although there are many articles concerning project managers in which the focus is typically on alerting the reader to the possibility of, or the effects of stress as a secondary issue within the article.

2. Discussion

Project managers, as leaders, are confronted with increasingly complex organisational and project environments, and their associated social challenges. Effective project leadership is essential for coping with the inherent social (interpersonal) and operational problems encountered within the project environment and managing the successful delivery of projects while coping with the factors that drive occupational stress. The complexity of the project environments and its associated occupational stressors was directly addressed by a single study participant when they acknowledged that “we’ve got to be very careful that we don’t burn them out”. Several other participants obliquely referred to the drivers and impacts of occupational stress by employing expression like “it can be quite bullish at times” and “the job is physically demanding” when discussing the cultural environment within their respective organisations.

Burns (1978) observed that leadership can be viewed as an influence process between individuals and as an organisational process of mobilising forces to change and reform social systems. In that light, effective project leadership can be viewed as a process that involves two levels of influence (individual and organisational) and two types of influence relationships (internal and external), see Figure 1.

Project leadership involves actions that directly influence occupational stressors and at the same time indirectly influences people by changing the formal policies, structure, and culture of the organisation through the delivery of the project outcomes. One study participant observed that the project is more likely to be successful and less stressful if the project manager “has that skill to read people, engage, and understand” acknowledging that the influence processes at the individual and organisational level are interrelated and that the two levels of influence must occur together in a mutually supportive way with careful timing and coordination.

	Type of relationship	
Level of influence	External	Internal
Individual Organisational	Creating and maintaining a network of relationships Exercising Influence Identifying strategic threats and opportunities Serving as the spokesperson for the project & (sponsoring) organisation Negotiating agreements and gaining cooperation and support from external actors	Setting project objectives and strategies Organising work packages Creating and maintaining a network of relationships Gaining commitment to project objectives Motivating internal actors to the objectives and strategies Maintaining cooperative relationships and teamwork

Figure 1 - Influence and relationship framework adapted from Portugal and Yukl (1994)

Internal project leadership includes setting the project objectives and strategies, organising the work activities to accomplish the objectives, motivating commitment to the objectives and strategies, and maintaining cooperative relationships and teamwork. External project leadership involves creating and maintaining a network of relationships with people outside of the project organisation and influencing outsiders, identifying strategic threats and opportunities, serving as the spokesperson for the project and sponsoring organisation, negotiating agreements that are acceptable to the sponsoring organisation, and gaining cooperation and support from outsiders on whom the sponsoring organisation depends to accomplish the project (Portugal and Yukl, 1994).

Within the project environment, there are many possible environmental sources of stress. These sources of stress, also known as stressors, can be grouped into categories as shown in Figure 2. The categories are: intrinsic factors associated with a job or profession (e.g. project management); the individual’s role in the organisation/project, career development opportunities, relationships at work, and factors associated with the organisation’s culture and structure. An individual’s characteristics such as: personality type, level of anxiety, level of neuroticism, and their ability to tolerate ambiguity leads them to understand and respond to these stressors differently. Additional external factors such as family problems, life crises, financial and other personal matters also influence how an individual will respond to stressors. Each of these factors contributes to the level of occupational stress experienced by the individual.

Previous studies of stress have indicated that there is an optimal amount of occupational stress in terms of its effects on an individual's performance. This optimum level of stress on the project should be of great interest to the project sponsor as it impacts the project manager's effectiveness and the project outcomes. Surprisingly only one participant directed their responses to the stress experienced by the project manager and the impacts it may have on project delivery. Several other participants made obtuse remarks concerning the performance of a project manager that could be loosely interpreted as an acknowledgement of the stress involved in projects. All participants are project sponsors and it was not clear that they understood the relationship between the project and the project manager's performance and occupational stress, the need to effectively manage stress in the project environment, and in turn the effectiveness and the health of the project manager. Effective project leadership behaviours increase the competence of a project manager and arguably result in a more efficient project delivery.

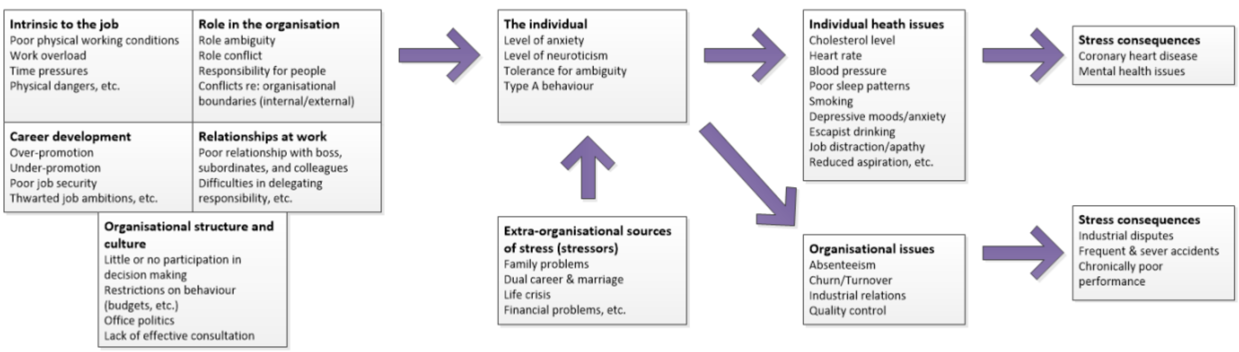

Figure 2 - Sources of stress and outcomes, adapted from Cooper & Marshall (2013)

Constructive feedback from the project sponsor would not only help the project manager do their work more effectively but also improves communication between the project sponsor, the project manager and other actors involved in the project, resulting in a reduction of occupational stressors. Several of the participants acknowledged the need to have effective communications with the project manager but the communications were primarily concerned with the management of project issues or mentoring the project manager into the "ways of the company". Social support and supervisory support provided by the project sponsor would act as a buffer to stressors placed upon the project managers which would, arguably, result in the dilution of the impact of the occupational stressors. The reduction in stressors may vary in accordance with the individual attributes of the project manager and the level of support provided by the project sponsor.

Stress that is higher or lower than the optimal amount results in steadily decreasing performance of the project manager and consequently an increasing risk of a poor project outcome. Performance under stress follows an inverted-U-shaped function known as the Yerkes-Dodson law (Anderson, 1976). Figure 3 shows the inverted U-shape function of the Yerkes-Dodson law's curvilinear relationship between the amount of stress felt by workers and their level of performance. It shows that both extremely low and high levels of stress tend to have a negative impact on an individual's performance. The Yerkes-Dodson curve suggest that for projects and project activities that are "too easy and of a routine nature" the project manager may feel a very low level of stress and therefore may not feel sufficiently motivated, challenged, or involved in the project to perform at their best.

Nearly two thirds of the participants were anxious about various aspects of the project manager's person-job fit attributes and their ability, as described in different ways by several participants, 'to get stuff done'.

Many of the participants were keen on increasing the job demands on the project manager by introducing more challenges, constraints, and a need to drive creative solutions to resolve problems within the project. The Yerkes-Dobson curve suggest that increasing the demand will tend to increase the project manager’s performance as they experience eustress up to a certain level of stress which corresponds to a range of stress for optimal performance.

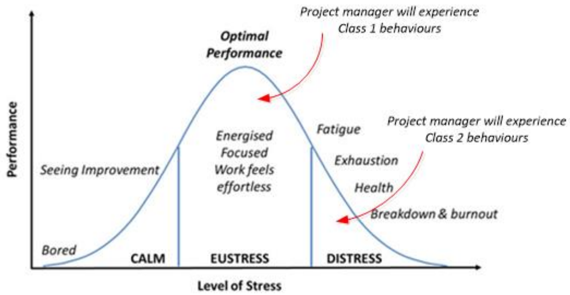

Figure 3 - Yerkes-Dobson's curve, adapted from Anderson (1976)

Increasing the level of stress beyond this point, the project manager’s performance will begin to deteriorate. This happens quite often when a project sponsor has unreasonable expectations and imposes unrealistic budget, time, and other constraints on the project. The level of motivation to solve a problem under high levels of stress becomes so high that the project manager's perception narrows to only obvious cues, and he/she ignores relevant information and may focus on reducing anxiety rather than performing project management tasks. When experiencing excessive levels of stress, the project manager experiences distress and may become agitated, or emotionally upset, or experience health problems, thus causing a significant reduction in their level of performance and have negative impacts on their health. At this point the project manager will switch from class 1 problem solving behaviours and focus on class 2 behaviours which emphasise emotional and defensive coping mechanisms leading to a reduction of task (project management) performance.

Increasing the job demands on a project manager by introducing more challenges, constraints, and a need for creative solutions will, as suggested by the Yerkes-Dobson curve, tend to increase the project manager’s performance as they experience eustress up to a certain level of stress which corresponds to a range of stress for optimal performance. If the level of stress increases beyond this point, the project manager’s performance will begin to deteriorate. This happens quite often when a project sponsor has unreasonable expectations and imposes unrealistic budget, time, and other constraints on the project. As previously noted, the level of motivation to solve a problem under high levels of stress becomes so high that the project manager's perception narrows to only obvious cues, and he/she ignores relevant information and may focus on reducing anxiety rather than performing project management tasks.

3. Concluding Remarks

During the interviews only one of the participants directly referred to the project manager, stress management, and the need for the project sponsor to beware that the project manager may be operating under considerable stress. The participant recognised that each project manager would have a different “stress threshold” and that the sponsor should be aware of the level of stress that is placed on an individual and the possibility of burn-out. Several other participants obliquely referred to the project manager being anxious, showing strain, or being overstretched. In these cases, the participant was not expressing concern for the project manager’s well-being or their ability to manage environmental stressors, it was inferred that the project manager wasn’t up to the task, when it may have simply been that the project manager was a “poor fit” to that particular project environment.

It is disturbing that only one participant considered that the welfare of the project manager to be a factor in their description of a competent project manager. It is a little reassuring that several other participants obliquely addressed stress, but it is difficult to explain why virtually every participant overlooked workplace stress when discussing their understanding of a competent project manager. It is possible that they overlooked stress due the organisational cultural factors, perhaps they consider stress to be a normal element within the workplace, or perhaps the topic is taboo, or perhaps the lines of communication between the participants and the project managers are not open and the signs of stress are missed. Regardless, stress has been investigated across many different professions since the 1930s and it is the responsibility of a project sponsor to be aware of the signs of stress in their team members.

Cooper et al. (1988) recognised that there was a relationship between workplace stress and an individual's well-being and their performance. Stress, it can be argued, is an unescapable but essential part of a project manager's working life. For the project manager, the workplace stands out as the most likely source of stress due to the amount of time that is spent in that environment.

The project environment is essentially a complex social environment. This was recognised by the participants, with that in mind they openly acknowledged that a person-environment (P-E) misalignment can cause problems in the management and implementation of a project and may even result in the possibility of a failed project. Considering the complexity of project environments, it is surprising that little attention has been given to work-induced stress within the project management industry although there are many studies on stress that have produced a long list of possible antecedents of burnout, the theoretical progress within the project environment has been limited. In addition, the very low acknowledgment by the participants of the negative impacts stress may have on both the project manager and the project is also surprising. This lack of acknowledgement strongly suggests that additional research on stress focused on the project environment is warranted and that both project sponsors and project managers need to be made aware of the antecedents to stress and the consequences of stress both in the personal and business sense.

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Broadband Telecommunication Deployment: A Supply Side Analysis of Penetration Drivers in A Developing Country Case

Nwakanma, Ifeanyi Cosmas
Lecturer II, Information Management Technology
Federal University of Technology, Owerri, Imo State, Nigeria
Ifeanyi.nwakanma@futo.edu.ng; fraircos@yahoo.com +2348038113290
Ogbonna, Achimba Chibueze
Professor,Backcock University, Ilissan-Remo, Ogun State, Nigeria,
ogbonnac@babcock.edu.ng
Asiegbu, Baldwin Chukwunanu
Professor,Information Management Technology
Federal University of Technology,Owerri,Imo State, Nigeria
Baldwin.asiegbu@futo.edu.ng; cbasiegbu@yahoo.com
Udunwa, Ikenna Augustine
Lecturer I,Information Management Technology
Federal University of Technologyy,Owerri, Imo State, Nigeria
Udunwa123@gmail.com
Nwokonkwo, Obi C.
Senior Lecturer, Information Management Technology
Federal University of Technology Owerri , Imo State,, Nigeria
engrobinwokonkwo@yahoo.com

Abstract

It is common to reference technology in the built environment to infrastructure like housing, water works, roads, bridges, and etcetera whenever construction is being discussed by even some supposedly informed persons. However, 'Broadband' is not just a technology but is fast becoming an important infrastructure needed to help the economic growth of any economy. Broadband availability/penetration, like other types of infrastructure, remains a serious development drawback in developing/least developed world regions like Nigeria which suffer a combination of 'digital' disadvantage and tight national budgets/low receipts hence providing high investment potential that has continued to attract international construction projects/ funding thus justifying the need to investigate the supply-side drivers responsible for broadband provision as an aid to private investors, and national governments policy-wise. The result of analysis reveals that ease of doing business, competiveness and corruption index collectively significantly affect broadband penetration

Keywords: broadband telecommunication technology, infrastructure, broadband penetration, penetration drivers, development.

INTRODUCTION

The World Trade Organization(WTO,2017), opines that ' technology' remains one of the three "pillars" by which to identify "smart destinations", including in our view, broadband technology, as part of telecommunication infrastructure with infrastructure denoting the ' basic structures/facilities essential for modern economic growth and development(Kadiri et al,2015). On their part, The World Bank Telecommunication Sector Reform (WBTSR, 1991) had since rightly noted the contribution of telecommunication infrastructure to economic expansion/development and/or growth) hence denoting infrastructure as a development index as corroborated by the International Monetary Fund (IMF, 2010).

Broadband technology simply recognizes those technologies that make use of fixed or mobile connections for high-speed/high capacity data communication (FSR, 2011) with data speeds not below 256kbits/s (Chinemerem, Awodele, Kuyoro & Izang, 2015; FSR, 2011). Also significant is the huge digital imbalance between developed and developing/least developing countries as noted by sources such as ITU (2015); Kojo, (2014) respectively indicative of the following: internet access of households (80% vs.34%; 7% vs.46% [world average])(ITU,2015).The above picture clearly tilts the investment potential in favor developing/least developed world regions as noted by GSMA(2014), especially for Internet users. With complexity, short time-to-market, competition, continuous improvement, triple bottom line(planet, people, profit) as major considerations, procurement/management collaboration across national/regional boundaries via international projects becomes necessary and foreign private funding may be needed since infrastructure, especially the "telecommunication sub-sector is capital intensive"(Ebinimi,2015). Appropriate business models that factor in government facilitation through public policy also become necessary in order to achieve success as understood in this paper. The combined reference above to international projects and foreign funding accords with the idea of foreign direct investment (FDI), itself a "trending idea" (Ogbonna and Ohiri, 2017) in the twenty first century construction experience. Notwithstanding its criticisms (McGee and Edwards, 2010; Loewendahl, 2016), FDI simply refers to international capital movement (Nayak and Choudhury, 2014) or the ownership of production facilities by foreigners (Adrianony, 2016). The combination of 'digital imbalance' and 'investment potential tilt' referenced earlier compels a developing country case with which Nigeria fits as follows: low penetration(Kojo,2014; Chinemerem et al,2015); gross domestic product(GDP) contribution (8.5%,2015;9.8%,2016)(Ebinimi,2015; NCC,2016); sector investment volume($68bn,2016;FDI($38bn,2016), subscriber estimate -153m(approx.)(Ojobo,2016); investment potential-increasing data consumption, digital entrepreneurship, and large youth population(GSMA,2014); 97% estimated potential penetration rate (ITU,2015); 105.7% teledensity(2015)(NCC,2016). Related to the above scenario are the following challenges: high tariff/connectivity cost(Ebinimi,2015; Nwakanma, Asiegbu and Amadi,2012;Ezeh & Diala, 2014; GSMA,2014; low yield towards economic growth, domination by external players(Abdulahi,2013); absence of impact analysis(Okereke, Onwe & Agboola,2009); absence of proper business model(Posu,2006); and low private sector investment(GSMA,2014).

Since 'socio-economic impact' should be seen to directly convert to sustainable economic development, mobile broadband infrastructure can also be viewed under the strategic development goals (SDGs) agenda. Although more properly coming under development goal 9(industry, innovation and infrastructure), it can loop backwards to such goals as 4(quality of education); 10(reduced inequality); 11(sustainable cities/communities); 12(responsible consumption) (United Nations Development Programme, 2015) all of which can be seen to interest 21st century international construction stakeholders. The above indicated focus follows the recognition of "make or mar" impact of the nature and timing of government intervention on broadband penetration(Broadband Commission, 2015) which is exemplified by 10% compared to the planned 30%(National Broadband Plan(2013-2018) against 30% already achieved in countries like Ghana, Kenya, South Africa and Egypt (Ekpeke,2015). Notwithstanding the socio-economic impact potential of mobile broadband infrastructure, private sector investment in the area remains grossly insufficient for reasons including the interplay between poor understanding of consumer needs, focus on core market competition, network roll-out and regulation costs, and absence of appropriate business model (GSMA, 2014). The FDI slant of this paper therefore agrees with the need for a business model that can increasingly and sustainably stimulate private sector investment that is properly facilitated by the public sector as noted by Katz (2010) hence the further need to ascertain drivers of broadband penetration using a supply-side perspective.

Broadband Technology and Economic Development: The Supply-Side Perspective

Preamble

Whereas business models tend to capture the value creation, delivery and capture mechanism employed to deliver a service including offering strategies, infrastructure, organization, trading practices and operational processes and policies (Katz, 2010), supply-side policies aim to reduce an operator's deployment costs or enhance private operator's access to market and finally, directly developing broadband infrastructure especially through public-private partnerships (FSR, 2011).

The relationship between telecommunication technology and economic development/growth has been recorded by several studies producing utilitarian business models such Jipp(1963), Bebee et al(1967) who using data from 29 countries at different stages of development and others but noted the absence of modern technology as a major obstacle to growth and poverty reduction.

Three key issues characterizing the supply-side approach relate to: presence several operators under a condition of high urban business and residential density; primarily residential density; and a low one operator typified by Nigeria before 2001 with sparse rural residential density.

Related Work and Research Gap

Research as early as Jipp (1963), and Bebee et al (1967), using 29 countries' data at different stages of development, and Hardy (1980) and Moss (1981) many studies have correlated telecommunication infrastructure and economic development. While Abutateb, et al (2001) found the absence of modern technology as a major obstacle to growth and poverty reduction, and Nandi and Dholakia (1994) did so for telephone infrastructure and economic development connecting a number of factors, Madden, et al (1998) tried to empirically relate gross fixed investment, telecommunication infrastructure investment, and economic growth for a sample of transitional countries of central and Eastern Europe. Kim et al (1997) showed telecommunication infrastructure to impact economic growth more than other traditional infrastructure as corroborated by Sridhar and Sridhar (2005) and noted for Nigeria by Juwah (2011) who noted that GDP rose from 0.06% to 3.66% from 1999 to 2009.

In terms of methodology, this paper notes the following: De Long and summer (1993) - regression analysis as well as instrumental variables; Cronin et al (1993b) -Peterson Index; Cronin et al (1991) - the Grange, Sims and modified Sims tests to confirm the existence of feedback process in which economic activity and growth stimulates demand for telecommunication services. On his part, Gupta (2000) submitted an estimate that 1% growth in telecommunication services generates 3% growth in the economy while Ncube, Gasela & Hatting (2013) used regression analysis and applications of linear response and surface analysis techniques and concluded that broadband penetration is a function of factors such as: innovation, freedom from corruption, fixed telephone subscribers per hundred, and institutional reforms just as Ajunwa's (2016) review concluded on the influences on broadband demand gap as: economic barrier, limited technology training, slow assimilation of broadband, uneven telecommunication network deployment and epileptic power supply. The difference in this paper's approach however, is that unlike Oshone & Anuoluwapo (2014) which though similar , did not decipher factors responsible for the growth or otherwise of the broadband this paper used distributed questionnaires (similar to Ncube, Gasela & Hatting (above), as well as secondary data while also analysing the relationship between the supply-side factors thereby filling the two gaps. On one hand, Verboven (2001) established broadband penetration as proxied by mobile telephony: delay in issuing licenses, persisting cross country differences, introduction of competition, higher GDP and larger fixed networks while Ah & Lee's (1999) 64-country study concluded that subscribership rate depends on country specific factors which include: national wealth, level of technological change and industrialisation, fixed network facilities, GDP and existing tariff systems. Rossotto, Kerf & Rohlfs (2000) simply concluded that competition increases mobile penetration by increasing market size and drove incumbent fixed network operators to improve their provision of fixed

services. The missing link in the above literature pieces is the absence of correlationship between demand growths for mobile telephony to other factors such as: calling party pays (CPP), or Receiving Party Pays (RPP) and innovative pricing arrangements e.g. multi-party tariffs and prepaid services which were covered in the work of Banerjee & Ros (2004) who raised other fundamental points as monopoly, transition from analogue to digital, mobile competition and end of monopoly, developing countries opening up to foreign investments, regulations not being so rigid on pricing of mobile telecommunication, creation of specialized regulatory structures and institutions known as National Regulatory agencies (NRA) which is known in Nigeria as Nigerian Communication Commission (NCC).
Incidentally, Banerjee & Ros (2004), excluded the entire African Continent in their work citing non-availability of complete and reliable data as basis which this paper remedies using Nigeria as a case to identify what all researchers have called 'region-specific' findings and specific drivers that may be peculiar to the Africa instead of simply generalizing as in Banerjee & Ros (2004).

Results and Discussion

The analysis used data from trading economics, and Nigerian Communication commission (NCC) for the 2008 to 2016 time period, as well as Internet live statistics. Data was available only for corruption index, competitiveness, ease of doing business and taxation. These were regressed against the number of internet users for the period under review. Table 1 shows the secondary data.

Table1: Data of Supply-side factors affecting broadband penetration.

Year	Corruption Index (X1)	Competitiveness(X2)	Ease of Doing business(X3)	Corporate Tax rate X4	Broadband Penetration (% of Internet Users) Y
2008	27	3.69	120	**30**	**15.9**
2009	25	3.81	125	**30**	**20**
2010	24	3.64	133	**30**	**24**
2011	24	3.37	133	**30**	**28.4**
2012	27	3.44	138	**30**	**32.8**
2013	25	3.67	147	**30**	**38**
2014	27	3.57	170	**30**	**42.7**
2015	26	3.43	170	**30**	**45.1**
2016	28	3.46	169	**30**	**46.1**

Source: NCC, Trending economics and Internet Live statistics (2017)

Using Statistical Package for Social Sciences (SPSS) software yielded the Table 2-Table 6 below.

Table 2: Descriptive Statistics

	Mean	Std. Deviation	N
Broadband Penetration	32.5556	11.17443	9
Corruption Index	25.8889	1.45297	9
Competitiveness	3.5644	.14800	9
Corporate tax rate	30.0000	.00000	9

Table 2, the descriptive statistics of the variables studied produced the following: broadband penetration average as **32.55% (**past 9 years); corruption index averaged: **25.89**; competitiveness: 3.56, ease of doing business: 145; and corporate tax remained unchanged: **30%**. Table 3 below revealed that ease of doing business correlated as high as 0.96 implying that broadband penetration improves on ease of doing business followed by corruption index, and competiveness while corporate tax remained unchanged in the last 9 years; it is understandable that it does not correlate with broadband penetration. However, a look at the t-significance further showed that Corruption index only, seemed not to have a significant effect when considered alone.

Table 3: Correlations

		Broadband Penetration
Pearson Correlation	Broadband Penetration	1.000
	Corruption Index	.411
	Competitiveness	-.568
	Ease of Doing business	.964
	Corporate tax rate	.
Sig. (1-tailed)	Broadband Penetration	.
	Corruption Index	.136
	Competitiveness	.055
	Ease of Doing business	.000
	Corporate tax rate	.000

a. Dependent Variable: Broadband Penetration
b. All requested variables entered.

Table 4: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics		
					R Square Change	F Change	df1
1	.972[a]	.946	.913	3.29465	.946	29.009	3

a. Predictors: (Constant), ease of Doing business, Corruption Index, Competitiveness

Having an R-square value of **0.946** or 94.6% showed that the independent variables account reasonably for the change in the broadband penetration in Nigeria. This was confirmed using ANOVA table 5 which shows that Sig-F change is **0.001** which is lower than **0.05** thus we conclude that the independent variables collectively have significant effect on the broadband penetration in Nigeria.

Table 5: ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	944.669	3	314.890	29.009	.001[b]
	Residual	54.274	5	10.855		
	Total	998.942	8			

a. Dependent Variable: Broadband Penetration
b. Predictors: (Constant), ease of Doing business, Corruption Index, Competitiveness

Table 6: Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.879	41.287		.070	.947
	Corruption Index	-.278	.904	-.036	-.308	.771
	Competitiveness	-10.469	8.962	-.139	-1.168	.295
	Ease of Doing business	.512	.074	.915	6.957	.001

a. Dependent Variable: Broadband Penetration

Based on table 6, the coefficient regression model can be formulated but corporate tax was removed since it does not correlate because it has remained constant for the past 9 years. However, the model is given as:

Broadband Penetration = 2.879-0.278(Corruption Index)-10.469 (Competitiveness) +0.512 (Ease of doing Business) equation 1

This model is **94.6%** reliable for inference making. It also means that reduction in corruption and removal of forces that prevent competition in the telecommunication sector will improve both broadband penetration and ease of doing business in Nigeria. These findings accord with basic economics but specifically in Nigeria, the ease of doing business in the telecommunication sector will involve but not be limited to the following: improvement in power supply via telecommunication infrastructure development/operation cost thereby reducing cost of broadband provision especially that of right of way (**ROW**) encountered in major states in Nigeria. This can be achieved by a national or state dry duct infrastructure pool to be subscribed to by service providers rather than the present method of provision by each provider and which are not protected from damage by others, especially, had infrastructure such as roads, resulting from the absence /non-enforcement of clear-cut policies. Similarly, the issues of multiple taxation for ROW at different levels of government, and co-location of facilities/equipment need to become policy features in order to ease doing business and increase roll-out times in Nigeria.

Summary, Conclusion and Recommendations

1. Licensing new operators to deliver broadband services using the latest technologies
2. Encourage and support policies and solutions that will urgently resolve the infrastructure crisis as it relates to power supply and inter-city broadband data transmission networks
3. Remove bottlenecks that prevent cabling companies from freely securing rights of way
4. Identifying factors affecting fixed telephone companies and ISPs towards (a) gaining a deeper understanding of the problems. (b) Designing policies to reverse the negative trends.
5. Creation of demand for broadband access through creation of local content and e-services like e-government, e-commerce, e-learning etc (Ajayi, 2016)

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Acknowledgement: Authors wish to thank the Federal University of Technology Owerri Nigeria and Tertiary Education Trust Fund for sponsoring this paper

Applications of Nanomaterials in Pavement Engineering: A Review

Vasileios C. Papadimitropoulos, Stylianos K. Karatzas, Athanasios P. Chassiakos
Department of Civil Engineering, University of Patras, Patras, Greece
infovpa@gmail.com, ksteliosk@hotmail.com, a.chassiakos@upatras.gr

Abstract

Various types of bituminous mixtures are used in the construction of flexible pavements, depending on the requirements of the project. Asphalt is a body of solid dark color substance, refined from crude oil. By mixing asphalt with additives like sand, stone and gravel, asphalt binds all of them together into what is called asphalt pavement. A systematic effort has been made to develop asphalt mixtures with improved properties. Although bituminous materials are mainly used on a large scale and in bulky quantities, the macroscopic mechanical behavior of these materials continues to essentially depend on the extent of microstructure and physical properties in micro and nano-scale. Nowadays, one of the most interesting areas of asphalt research involves the use of nanomaterials. New research efforts regarding the development of nanomaterials for use in asphalt indicate the potential for improvement in durability, mechanical and physical properties resulting thus in new multidisciplinary research fields with synergy of academia and industrial retrospective partners. This paper presents several types of nanomaterials with their properties, the ways that they can be integrated in new asphalt mixture development, potential applications in pavement engineering and pavement charactristic improvements, and finaly current trends and challenges in obtaining such results.

Keywords

nanomaterials, asphalt, pavement, material properties

1. Introduction

Nanotechnology is the consideration and control of matter at the nanoscale. More specifically, nanotechnology is manipulation of matter on an atomic, molecular, and supramolecular scale. A common description of nanotechnology refers to the particular technological goal of precisely manipulating atoms and molecules for fabrication of macroscale products (Drexler, 1992). According to Whatmore and Corbett (1995), the subject of nanotechnology includes "almost any materials or devices which are structured on the nanometer scale in order to perform functions or obtain characteristics which could not otherwise be achieved". Nanotechnology is not just a science that deals with materials in very minor dimensions, but a science that exploits the unique physical, chemical, mechanical and optical properties of materials on this scale. Some nanostructured materials are stronger or have different magnetic properties compared to other shapes or dimensions of the same material. Some others, present better performance as far as the heat and electricity conductivity are concerned. They can also become chemically more drastic or reflect slightly better or even change color as their size or structure changes. As that, the utilization of nanotechnology in pavement materials is considered an area with high potentiality, strong enough to amend commonly used materials (Faruqi *et al*., 2015).

2. Nanotechnology in asphalt pavements

The continious increasing traffic loads and volume in conjuction with the rising cost of asphalt as a byproduct of crude oil, makes the need for improved durability, safety and efficiency of asphalt pavements imperative and this can be done by means of asphalt modification (Partl, 2004). Nanotechnology gradually is enganged more and more into the field of asphalt modification. Dreamlike effects of nanomaterials have now been brought to enhance and augment the perfromance of asphalt. Several trials and efforts have been initiated in the scope of preparation of modified asphalt for realizing the mechanism of modification and the subsequent improvement in performance (Changqing *et al*., 2013). In pavement engineering reasearch, nanotechnology is employed as a form of new material, device and system at the molecular level. It is anticipated that the use of nanotechnology in the improvement of asphalt pavements will craft the conditions for manufacturing of more durable and longer lasting pavements that can be utilized to key infrastructure projects like airfields, ports and highways. That can be done by adding various nanoparticles, the production of which is continously under reaserach and development for making them easier in mix process and more competive in cost (Faruqi, 2015). As nanotechnology reaseach follows a fast-track path, introduction of nanomaterials in asphalt pavements advances in a parallel hish ascending pathway. More than that, the unique qualities that nanomaterials exhibit, such as high temperature sensitivity, high ductility, large surface area, high strain resistance along with low electrical resistivity, create additional reasons for such soaring development (Yang *et al*., 2010 and Veytskin, 2015).

3. Nanomaterials in use for modified asphalt pavements

Nanomaterials, due to their nature, exert specific dimension properties. As a result, they exhibit specific characteristics, qualities and unique features compared to commonly used materials, making likewise feasible their integration as additives in asphalt pavements. Ordinary pavement materials can hardly meet the operational requirements for present and future highways as well as pavement construction technology. Consequently, pavement materials of enhanced quality, increased safety, higher realibility and more environmental friendly features, are in high demand. The dispersion of nanomaterials within asphalt materials may considerably enhance certain properties of asphalt constituents, e.g., visco-elasticity, high temperature effects, resistance to aging, fatigue and moisture (Ruoyu, 2017). The nanomaterials applied in asphalt pavement engineering with their specific properties are categorized in the next sections.

3.1 Carbon nanotubes (CNT)

Amid various nanoparticles that have been considered as potential asphalt binder modifiers, *Carbon Nanotubes (CNTs)* have attracted an increasing interest (Yang, 2013). CNTs belong to nanocarbons which are among the most promising materials developed in recent years. Nanocarbons also include fullerenes, nanodiamond, onions, various hybrid forms and 3-dimensional structures based on these. Several years ago, these materials were available in milligram-scale quantities while now many of them are produced by tones per year. Carbon nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure. These cylindrical carbon molecules exhibit uncommon properties yet valuable for nanotechnology and other fields of material science and technology. On account of the material exceptional strength and stiffness, nanotubes have been constructed with length-to-diameter ratio of up to 132.000.000:1, significantly larger than for any other material (Wang, 2009).

3.2 Nano-clay

Nanoclays are nanoparticles of layered mineral silicates. As layered silicate is termed the clay that has a layer thickness ranging from 1 to 100 nm and is broadly utilized in the modification of matrices to improve mechanical and thermal properties. Depending on chemical composition and nanoparticle morphology, nanoclays are ordered into a number of classes such as *montmorillonite, bentonite, kaolinite, hectorite, and halloysite* (Sigma-Aldrich, 2018a). It is the sort of nano-particles mostly used for material modification, due to their low cost of production and ample availability in nature.

Two main types of nano-clays are utilized for modifying asphalt binder. The first is the Non Modified Nano-clay (NMN) asphalt and the other one is the the Polymer Modified Nano-clay (PMN) asphalt. Out of two nano-clays, the NMN is the most commonly layered silicate used, with a 2 to 1 layered configuration clay consisting of one octahedral alumina sheet sandwiched in the middle of two tetrahedral silica that was proposed by Ray and Okamoto (Ray and Okamoto, 2003) .

3.3 Nano-fibers

Nanofibers are fibers with diameters in the nanometer range. Nanofibers can be produced from different polymers (natural or synthetic) and, thus, have different physical properties and application potential while they belong also to the wider family of nanocarbons (Khajavi *et al.*, 2016). The diameters of nanofibers depend on the type of polymer used and the method of production. All polymer nanofibers are unique due to their large surface area-to-volume ratio, high porosity, appreciable mechanical strength, and flexibility in functionalization compared to their microfiber equivalents.

Carbon Nano-Fibers (CNFs), apart from having large surface area and high aspect ratio (like all nanomaterials), present also good interfacial bonding and high tensile modulus. Carbon nanofibers are discontinuous, highly graphitic, highly compatible with most polymer processing techniques, and can be dispersed in an isotropic or anisotropic mode. Also, they have excellent mechanical properties, high electrical conductivity, and high thermal conductivity, which can be imparted to a wide range of matrices including thermoplastics, thermosets, elastomers, ceramics, and metals. Carbon nanofibers have a unique surface state, which facilitates functionalization and other surface modification techniques to tailor/engineer the nanofiber to the host polymer or application. Carbon nanofibers are available in a free-flowing powder form - typically 99% mass is in a fibrous form (Sigma-Aldrich, 2018b).

3.4 Nano-Silica (S_iO_2)

Silicon dioxide, also known as silica (from the Latin silex), is an inorganic material, namely an oxide of silicon with the chemical formula S_iO_2, most commonly found in nature as quartz and in various living organisms. In many areas all over the earth, silica is the main constituent of sand while primarily it is produced from silica precursors. Silica is one of the most complex and most abundant families of materials, existing as a compound of several minerals and as synthetic product. Silica nanoparticles have been utilized in industrial applications for reinforcing the elastomers as a rheological solute (Chrissafis *et al.,* 2008). The main advantage of this nanomaterial is the low production cost compared to its high performance prospect.

3.5 Nano-T_iO_2

Titanium dioxide nanoparticles, also called ultrafine titanium dioxide, are particles of titanium dioxide (T_iO_2) with diameters less than 100 nm. Ultrafine TiO_2 is regarded as one of the three most produced nanomaterials, along with silicon dioxide nanoparticles and zinc oxide nanoparticles. It is the second most marketed nanomaterial in consumer products, after silver nanoparticles.

In nature, titanium dioxide is minly found in the form of rutile, anatase and brookite. In particular, nanoscale titanium dioxide consists of 80% anatase and 20% of rutile. Nano titanium dioxide, compared to ordinary one, exerts very large surface area, very small diameter and significatly low opacity. Due to these distinctive properties, nano titanium dioxide is utilized by researchers as performance improvement additive in modified asphalts (Chen, 2010).

3.6 Nanophosphors

Nanophosphors are nanoscale crystalline structures with a size depedent bandgap that can be altered to change the color of light. Nanophosphors can be defined as nanoparticles of transparent dielectrics (hosts) doped with optically active ions (activators), so that the emission of light happens due to the electronic transitions between the levels of the impurity ions inside the bandgap of the host (characteristic luminescence) (Kelsall *et al.*, 2004).

3.7 Graphene and Graphene Oxide (GO)

Graphene and *Graphene Oxide (GO)* are regarded as two of the most promising materials because of their surface area size along with exceptional electrical and physical properties. Given their considerable production and purchasing cost, they were hardly studied in the traditional material science. Nowdays, as both nanotechnology and nanomaterial development are subjects of high concern and graphene and GO are much cheaper than before, due to their production process improvement, these materials are progessively introduced in the construction industry. Graphene plays a key role in the families of nano-materials, following its excellent physical and electrical properties, and lately is used to improve polymer properties.

4. Applications of Nanotechnology in Pavements

The construction industry pays special attention to nanotechnology and nanomaterial developments and innovations appreciating novel advances that can trigger market growth. It appears that the products generated out of the nanotechnology research and development can considerably treat contemporary construction difficulties and may alternate the requirement of the construction process. The major applications in pavements engineering are presented in the folowing sections.

4.1 Pavement surface characteristics improvement

Using nanosilica in the base asphalt binder, the viscosity indexes of nanomodified asphalt binder are slightly reduced. Reduced viscosity of the binder indicates a lower compaction temperature and lower energy consumption. Mixing of nanosilica into the asphalt can enhance the recovery ability of asphalt binders. The anti-aging and fatigue cracking performance of nanosilica-modified asphalt binder and mixture are improved as well as the rutting resistance and anti-stripping property. Yet, adding nanosilica into asphalt binder does not greatly affect the low-temperature properties of asphalt binders and mixtures (Yao *et al.,* 2012).

4.2 Physical properties enhancement

The use of CNTs to bituminous binders and mixtures have an impact to various properties of them. In particular, it can significantly extent its rheological properties (Khattak *et al.,* 2012). Furthermore, it results in underlayer thichness reduction and, therefore, stone material consumption (Motlagh *et al.,* 2012). Moreover, it can contribute in rutting resistance enhancement (Amirkhanian *et al.,* 2011) and to reduced sensitivity to oxidatives (Santagata *et al.,* 2012).Various physical properties of the bitumen (such as stiffness and tensile strength, tensile modulus, flexural strength and modulus thermal stability) can be enhanced when it is modified with small amounts of nano-clay, on the condition that the clay is dispersed at the nano-scopic level. Generally, the elasticity of the nanoclay modified bitumen is much higher and the dissipation of mechanical energy is much lower than in the case of unmodified bitumen (Jahromi and Khodaii 2009). Adding nanoclay in asphalt normally increases the viscosity of asphalt binders and improves the rutting and fatigue resistance of asphalt mixtures. Research has shown that even a small percentage of nanoclay could significantly improve the compressive and shear strength of thermoplastic materials (Ruoyu, 2017). Adding T_iO_2 to bitumen, results in higher softening point than the base bitumen. It is clearly observed that the bitumen performance is improved againt rutting, while its visco-elastic behavior is improved at higher temperatures. Moreover, it results in a decrease of penetration value compared to the control bitumen as well as in an increase of viscosity due to the improved bond between bitumen particles, which is developed by the integration of nano particles. Finally, the enhanced performance of bitumen in the softening point tests makes it more sensitive to the temperature changes (Sadeghnejad, 2016).

4.3 Micro-cracks prevention

It is thought that the high aspect ratio of fiber can produce a good network of nanocomposite. As that, the bridge-link effect of nanofibers can effectively prevent the development of micro-cracks under the interaction of heavy vehicle loading. Accordingly, using CNFs in asphalt binder enhances its mechanical and rheological properties.

4.4 Safety improvement

Nanophosphors can be added to traditional pavement materials such as concrete, bitumen and road paint to enable these materials to become luminescent after exposure to light. If the road can act as the source of the light it can play a role in improving road safety as the source of the light is not depedent on external power.

4.5 Sensoring

One of the widely-mentioned in research potential of nanomaterials is the development of sensors that act as part of the substrate that is being observed, thereby allowing very fine measurements on a small scale and obviating the need to add external sensors to a system (Goddard *et al.,* 2007). The application of CNTs in traffic monitoring is an example of such application (Shi and Chung 1999). In this type of applications, data transfer from sensor to a data acquisition device and data analysis still require further work, especially if the sensors are being distributed inside a pavement of several kilometers length. Also, supported graphene layers and various forms of graphene films offer the ultimate sensitivity to detect tiny stimuli (from low concentrations) due to their large surface-to-volume ratio, while graphene membrane sensors can also benefit from their excellent mechanical properties, e.g., high rigidity, flexibility and strength. Another important parameter of sensors is specificity which refers to the detection of just one specific substance and no other. To do so, the graphene surface needs to be functionalized.

5. Nanomaterial cost

The cost of most nanotechnology equipment and materials are currently relatively high. This is partly due to the novelty of the technology but also to the complexity of the equipment. However, in the case of the nanomaterials, costs have shown to decrease over time. The expectation is that as manufacturing technologies improve, the costs of the materials will decrease. For example, since 1990 the cost of producing CNTs has dropped by the order of 100 and may reach lower prices in the future.

For asphalt pavements, bitumen is a by-product of fuel production from crude oil. In typical asphalt pavements, the bitumen comprises about 0.5 percent of the mass and between 5 and 17 percent of the cost of asphalt concrete. As the crude oil reserves are being globaly depleted, the price of bitumen may increase drastically in the future. Therefore, nanotechnology can play a role in alleviating this problem (Gopalakrishnan *et. al.,* 2011). Furthermore, when dealing with the potential of nanomaterial application in pavement engineering, both construction and maintenance costs needs to be evaluated with focus on the short term, long term and life cycle cost aspects. In terms of maintenance costs, actions that can ensure minimum maintenance of pavements have a direct impact on the life-cycle cost as well as on delay impacts during the maintenance period, which can be prevented by the development of automatic crack filters and treatment corrosion of reinforcement. Also, the pavemant service life can in general be increased through the improvement of pavement resistance to environmental acts. Developing stronger materials, the required material quantities are reduced (e.g., thinner pavement layers), affecting accordingly the construction cost. Life-cycle effects in terms of pavement durability enhancement and reduced maintenance requirements should be included in any cost evaluation.

6. Trends and Challenges

Nanomaterials (especially Graphene-based ones) are expected to bring new solutions to current industrial challenges related to coomunication, energy generation and storage applications. Asphalt pavements are excellent materials when it comes to solar energy utilization. They are bare surfaces exposed directly to sun and, because of their low thermal conductivity and large heat capacity, they present considerable temperature increase. This is the point where the superior thermal properties of graphene can be nicely exploited. Adding a small amount of graphene would have a negligible impact on heat capacity, increasing conductivity and making the pavement an efficient heat transfer mechanism. Adding the potential of future graphene-based production of light and flexible PV cells, highly sustainable biomimic PV cells, light electrical storage systems, as well as light hydrogen storage systems, 'smart roads' could be develped. For example graphene based energy harvesting systems and in-road energy storage can create powerful solutions for 'while on the move' vehicles charging systems (Ghavanini *et. al.,*2015).

Along with the promising trends of nanomaterials, there are also some issues to be considered. Unintended consequences to human health and the environment that might accompany development and use of nanomaterials should be considered and mitigate the potential risks during the design stage rather than downstream during manufacturing or customer use (e.g., when the material is already embedded in the pavement) (NNI, 2014). Another major challenge to implement nanotechnology is the scale effect. The unique pavement engineering environment with large volumes of material should always be considered for the evaluation of potential applications of nanotechnology. The effects on manufacturing capacity and performance of the nanomaterials, when combined with bulk aggregates and binders, should be evaluated to ensure that the beneficial (nanoscale) properties are still applicable and value adding at these scales.

7. Conclusions

It is clearly shown that the addition of nanomaterials can improve the performance of asphalt binders. In particular, properties like softening point and kinematics viscosity can be improved (increased) along with bitumen penetration (decreased). Furthermore, the tensile strength of the modified bitumen is improved compared to the non-modified one. The same applies for the rutting resistance which is considerably better than the standard one. So far, nanoparticles (considered as additives) were not very attractive for investigation by researchers due to their relatively higher cost compared to usual additives (e.g., polymers). Nowadays, the continious engangement of more and more researchers in the nanotechnology field has resulted in the development of many new innovative and low cost production methods for nanomaterials, making them also appropriate for use in materials like asphalt binders, providing promising results in the direction of being integrated to them. There are still many sophisticated applications under research and development for nanomaterial-modified asphalt mixtures in order to meet several expectancies in pavement engineering, such as health monitoring, traffic monitoring, developing materials with luminescent properties, electricity production & storage, and information transferring.

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Effective way to reduce financial loss by safety investment: Concept from Safety Management System

Kai-Chi Thomas Ying
(PhD candidate, RMIT, Australia)
(Lecturer, Vocational Training Council, Hong Kong)
kc_ying@vtc.edu.hk

Guomin (Kevin) Zhang
(Professor, RMIT, Australia)
kevin.zhang@rmit.edu.au

Sejeeva Setunge
(Professor, RMIT, Australia)
sejeeva.setunge@rmit.edu.au

Abstract

Financial loss induced by construction accident has been widely discussed by researchers. To reduce financial loss of accident, efficient safety investment is suggested. Parameters of safety investment have been reviewed and identified based on a research study in Hong Kong. Key parameters to reduce financial loss in a combined effect by quantitative analysis have been generated. Meanwhile, investment in safety equipment, training and promotion are recommended and particularly effective to reduce financial loss of accident. Supporting statement for safety equipment, training and promotion from the Safety Management System (SMS) has been reviewed and presented in this paper. This paper provides concepts how the construction stakeholders, proprietors and participants, follow the frameworks to reduce financial loss by safety investment in training, equipment and promotion.

Keywords

Safety Management System, financial loss, safety investment, Hong Kong

1. Introduction

Accident cases happen unexpectedly and leads to direct and indirect loss. Accident is unpredictable as the severity both, so far, are difficult to. However, it is believed that sufficient safety investment does help to reduce financial loss. From literature, safety investment has been affected by staffing input (Number of safety personnel and their salary, equipment input into the project, training input, promotion input and others). The concept of financial loss has been reviewed and it included different parameters such as day loss & compensation, loss after resuming work, medical services, fines & legal expenses, lost times of others, equipment/ plant loss, damaged materials, idle machinery and other losses. (Ying KC et. al, 2016).

Structured interviews have been conducted to investigate the relationship between safety investment and financial loss from June to December 2013 which to investigate the project safety investment and accident information in Hong Kong construction market. 109 projects and 940 accident cases have been recorded. Quantitative analysis has been applied to investigate the relationship between financial loss to independent variables. Statistical Package for the Social Sciences (SPSS) version 24 applied for analysing the data. Negative correlationship was found between financial loss and the independent variables. The relationship is an inversed parabolic shape curve and non-linear regression found that financial loss is significantly related to safety equipment, training and promotion input. Financial loss which is a monetary loss suffered from the contractor. The relationship between financial loss to independent variables has been generated. Relationship between financial loss to safety investment has also been investigated. It found that safety investments in safety equipment, training and promotion really help to reduce financial loss in construction industry. (Ying KC, 2018)

It is believed that sufficient safety input will not only improve the safety performance on construction sites, but also reduce the risk of major accidents, reduce the number of injuries of workers, control risk on construction sites, reduce the number of accidents & accident rate and finally, even reduce financial loss. In this paper, the writers introduces supporting statement according to the Safety Management System (SMS) in safety equipment, safety training and safety promotion respectively. The extracted idea is going to develop frameworks to let construction proprietors and participants know how to pay their effort in the three aspects.

Regarding safety equipment, safety training and safety promotion in Hong Kong construction industry, it should be refer to the code of practice on Safety Management (HKSAR 2002), guideline regarding inspection report of construction sites (HKSAR 2004a), local legislation requirement and the Factories & Industrial Undertakings Ordinance (F&IU Ordinance - Chapter 59 of the Hong Kong Legislation) (HKSAR 2017).

2. Literature Review

A good safety management system in a construction company is highly recommended and supported by scholars over the past decade. One of financial consideration related to the inclusion of a good safety management system is that it leads to a better safety performance on the construction site (low number of accident, low accident rate and less fine & claim). Safety management is an important aspect required by of OHSAS 18001 (Occupational Health and Safety Assessment Series 18001) and ISO 14001 (International Standard Series 14001). It is believed that good implementation of a safety management system does help to improve safety performance and hence reduce the financial loss of accident caused by accidents. Since safety equipment, training and promotion are parameters of Safety Management System, it found that effective safety input in safety equipment, safety training and safety promotion do help to improve the safety performance of construction project.

Hinze and Harrison (1981) who suggested a formal safety training and safety awards are good motivation to mitigate site accident. Sawacha et al. (1999) discussed the safety performance can be improved by adopted safety management system in UK.

Choudhry RM et al. (2008) summarized that effective implementation of an Safety, Health and Environmental (SH&E) system is likely to reduce the number of injuries, minimize the risk of major accident, control risks of activities, minimize production interruption, reduce materials & equipment damage, reduce the cost of insurance premium and cost of employee absences, minimize legal cost of accident, fines and reduce investigation time of accident. It not only provides a positive image to the company, good effect to reduce accident rate, but also induce a better competitiveness performance and economic- financial performance of the company.

Ismail Z. et al. (2012) summarized different safety factors, which are respected in different Safety Management System (SMS) from different countries. Meanwhile, Safety training (train to use safety equipment) and safety promotion are significant factors to improve the SMS. They summarized that safety equipment included Personal Protective Equipment (PPE), equipment to ensure safe work activities, first aid, emergency shutdown system, control system. In training, it included on-job training, toolbox meeting, briefing, seminar, and train up session to use safety equipment or PPE. Regarding safety promotion, they summarized as bonus, promotion, campaigns, motivation, merit rating and incentive. In their finding, better design and application of equipment and PPE contribute the best improvement in SMS.

Jannadi M.O. (1996) summarized 19 factors which affecting safety performance. In his findings, safety training is in a top rank factor to improve safety performance in both survey results from the Safety Officers and workers. Educating works to have good safety habits (input in safety promotion) and keeping tolls and equipment in good working condition (input in safety equipment) are both in high rank. In his findings, investment in safety training, safety equipment and safety promotion do help to improve safety performance of overall safety performance.

Sawacha E. et al. (1999) found out that provision of safety booklet is important for workers to understand the safety policy of the company, which is a sort of good safety promotion. Safety equipment is also important in their findings. However, safety training is rare important which is a bit different from other researchers. Researchers investigated elements of safety planning and control (SPC) model to improve safety performance where training and equipment are important elements. Further, (Lu CS and Yang CS, 2010) stated that training and promotion are important to improve safety behaviour which can help to improve overall safety performance by considering research study from container terminal experience in Tai Wan.

There are 14 elements of the Safety Management System (SMS) in Hong Kong (HKSAR 2002) which is believed to be a qualitative reference for good safety management. Safety Auditor and Safety Officers follow the concept and suggestion to inspect and revise the safety program of construction companies and projects.

In summary, researchers pinpointed different findings regarding factors in safety performance in different study. Safety equipment, training and promotion are identified as key parameters to improve the overall performance. The key parameters (safety equipment, training and promotion) can ready help to reduce financial loss of accident as well as safety performance.

3. Safety Equipment

Safety equipment is one of important safety input to improve safety performance in construction industry (Langford et al. 2000, Choudhry RM et al. 2008 and Ismail Z et al. 2012). Safety equipment includes hardware and software which is defined by Sawacha E et al. (1999) which pinpointed that good safety performance can reduce the economic loss due to accident and it can save 5 to 50 times of direct cost according to their study. They mentioned good safety performance included safety equipment, Personal Protective Equipment (PPE), first aid equipment, fire-fighting equipment, Emergency Shut-Down (ESD) and control system and any requirements of the industry are help to improve safety performance of construction project.

Ergonomic tools are highly recommended in construction industry in recent year. However, it is rare to apply ergonomic tools in construction industry when compared with manufacturing and transportation industry, which may because of high initial and implementation cost. Researchers suggested introducing the concept of ergonomic tools in safety equipment to improve safety performance. In this paper, the writers pinpoint the concept extracted from the SMS and highlight how safety equipment helps to improve safety performance. Regarding the Safety Management System (SMS), summary of concern area has been shown in Table 1.

Area	Description
In-house safety rule	• Introduction of general safety rule: maintenance of plant, machinery and equipment; provision, use and maintenance of personal protective equipment
Inspection programme	• To identify equipment deficiencies, such as problems caused by normal wear and tear and abuse or misuse of equipment arrangements for the preventive maintenance of plant and equipment
Hazard control programme	• Identifying training needs: the introduction of new equipment or technology • Reactive monitoring data (for example: where is the equipment placed) • The proprietor or contractor of the relevant industrial undertaking should carry out a programme to protect the workers in question by means of suitable personal protective equipment • Proper selection of PPE • satisfy legal and reporting requirements
Emergency preparedness	• An emergency control center – its location and resources (Necessary equipment stored) • facilities and equipment to meet the needs of emergencies (eg: fire-fighting equipment)
Evaluation, selection & control of sub-contractors	• Tender document: sub-contractors should provide PPE to workers
Job-hazard analysis	• Recent changes in procedures, standards or legislation • Recall method: invite designers, engineers, supervisor & workers (users) to identify the hazard • Procedures and measures to ensure the proper use of personal protective equipment (PPE) as the last resort
Accident control & hazard elimination	• Complete & written information concerning process material • Information should include code & legislation • In operation procedures & instruction should include the applicable safety precautions & contain appropriate information on safety implication • Plant & equipment should be used in proper way • Mechanical integrity programme should be provided
Occupational health assurance programme	• Information and advice from suppliers of equipment, chemicals and other materials used at work

	• Minimization of risk by means of personal protective equipment as a last resort • Consulting the suppliers of substances, plant and equipment about minimizing exposure

Table 1: Summary regarding safety equipment according to Safety Management System

4. Safety Training

Safety training is important. Choudhry RM et al. (2008) did a questionnaire survey in year 2005 and investigate the effectiveness of safety training for twenty construction sites in Hong Kong. They suggested end of module test and first aid training are useful. They studied only one company but provided good insight about how to improve safety training in construction industry.

Safety program includes reducing physical work demands and worker injuries through train up the workers to use relevant equipment. Sufficient safety training should be provided to the participants/ workers to train them how to use the Personal Protective Equipment (PPE) or the safety equipment. Researchers pointed out that ineffective training was a non-intentional error where the root cause is lack of a well-structured training program. Therefore, a comprehensive design in training program is necessary. The paper pinpoints the concerned area in safety training according to the SMS and shown in the Table 2.

Area	Description
Safety structure	**Senior management**: • Senior management of the company should have adequate information regarding the resources allocation for training. • Senior management of the company is encouraged to be understandable in safety matter. • Senior management is encourage to invited safety expert to formulate safety policy, safety training issue for the company • They should consult to safety advisor regarding the updated requirement and government policy **Manager & supervisor**: • Managers and Supervisors are encouraged to attend induction and on-going safety training. • They should allocate time and resource for their team member to attend safety training **Worker:** • They should participate in toolbox meetings and other safety activities • They should participate in the mandatory basic safety training according to the legislative requirement
Safety Training	• The company safety department prepares a safety training policy • The company safety department prepares setting out safety training objective • The company safety department prepares devise a plan to implement the policy and arrange for employees to receive the necessary training

	• The company safety department prepares standard of performance of the training • The company safety department prepares monitor & review the effectiveness of training • The company safety department prepares monitor & review training plan • The company safety department prepares adequate & proper documentation • The company safety department prepares on and off job training • Decide whether training is needed (eg: marine works, confine space etc...) • Organizational training need, Job related training & individual training • Training, instruction, coaching & problem-solving skills relevant to safety & health • Formulation training objective and methods • Determine what level of training should be provided • Evaluation of the effectiveness of training • Documentation of training record
Hazard control programme	• Adequate training when use PPE • Training record for the PPE usage
Accident/ incident investigation	• Record of training
Evaluation, selection & control of sub-contractors	• Training programme & standard of sub-contractor • Worker training requirement • Sub-contractor safety & health training programme • Monitoring system
Accident control & hazard elimination	• Training & competency of worker

Table 2: Summary regarding safety training according to Safety Management System

5. Safety Promotion

This is no restricted guideline regarding safety promotion according to the inspection report on construction site. Table 3 provides a summary extracted from the Safety Management System (SMS) manual which suggested area to be improved. From the idea of (Fang DP et al. 2006, Choudhry RM et al. 2008), safety promotion aims to improve safety attitude of workers and letting the workers know company policy and updated safety issue. Implementation of safety issue according to the legislative requirement is to let workers know the senior management of the company is concerned about safety.

Area	Description
Safety structure	• Senior Management: policy, resource, culture, company awareness • Manager, Supervisor: implementation of policy • Worker: mindset

Safety committees	• Organization of safety promotion activities such as safety competitions, exhibitions, safety incentive schemes, and safety suggestion schemes
Safety & health awareness	• Safety promotion approach: meetings & seminar • Promotion of safety to individuals • Promotion of safety through safety publications, posters • Promotion of safety through campaigns • Monitoring, record, review

Table 3: Summary regarding safety promotion according to Safety Management System

In Hong Kong, The Development Bureau and the Labor Department organize "Considerate Contractors Award Scheme", "Construction Safety Week" and "Construction Industry Safety Awards Scheme" every year to promote safety. The promotion scheme is not only a target of construction companies and workers but also of worker's family and stakeholders. Those promotion schemes raise the concern of construction safety to the public, and have therefore have a good reputation.

The Hong Kong Special Administrative Region (HKSAR) launched a "Pay for Safety Performance Merit Scheme (PFSPMS)" since year 2013. The aim of the scheme is to make the contractor pay more attention to safety. This merit scheme is a task-tie payment scheme, which is not linked to previous safety performance of the company but the particular project. The scheme is let the contractor strive for better safety performance of the project. (HKSAR, 2016). The scheme provides extra 1.7% of total contract sum for promotion provided that the contractor has:

- No reportable accident in the a month
- No notice of safety/ environmental prosecution received in a month
- Compliance of silver card for workers of specified trades in a month
- Half-yearly review of safety performance
- 12 month rolling accident frequency rate < 0.25 per 100,000 man hour
- Yearly review of safety performance. eg: no fatal accident in a year
- Achievement in safety campaign activities
- Final review of safety performance is good

6. Conclusion

A huge financial loss was generated in construction industry every year. To improve this matter, it is encouraged stakeholders (government department, clients, and concern groups) to pay more attention to the safety issue. Comprehensive structured interviews have been conducted from June – December 2013 in Hong Kong. Safety investment of Client, developers and contractors has been investigated through structured interviews. Meanwhile 109 valid projects and 940 accident cases have been recorded in the research study. Quantitative analysis method has been applied to investigate the relationship between safety investment and financial loss. According to the findings, it indicated that financial loss could be significantly reduced by safety equipment, training and promotion whereas important factors in the Safety Management System (SMS). Safety equipment, safety training and safety promotion are encouraged to be invested to reduce the financial loss of accident. (Ying KC, 2018).

This paper summarized the concept of safety equipment, safety training and safety promotion according to the Safety Management Plan (SMS) whereas Hong Kong as a reference. The paper also introduce the description of framework to guide the industrial participants how to work with effective safety equipment, safety training and safety promotion. The aim of the framework is also to provide guideline to (i) senior management how to reduce financial loss by providing safety equipment, training and promotion in more detail and (ii) the participants understand their right and obligation in construction site and how to equip themselves properly.

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Concept of "Efficient Coordination Zone" relating to Truckmixer Deliveries Serving Construction Sites

Michael Anson
Professor Emeritus, Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Hong Kong
clanson@polyu.edu.hk

Kai-Chi Thomas Ying
Lecturer, Vocational Training Council, Hong Kong
PhD Candidate, RMIT, Australia
kc_ying@vtc.edu.hk

Ming-Fung Francis Siu
Assistant Professor, Department of Building and Real Estate, Faculty of Construction and Environment, The Hong Kong Polytechnic University, Hong Kong
francis.siu@polyu.edu.hk

Abstract
Matching the provision of concrete delivered by truckmixers to the needs of the crew placing concrete on site is difficult. In general, a placing crew spends some time idle, waiting for concrete to arrive on site, and yet, at other times, on the same pour, truckmixers form a queue waiting to be unloaded. The paper presents observations deriving from many pours of concrete in Hong Kong, of the amount of enforced waiting by the placing crew and the amount of enforced truckmixer waiting on site to be unloaded. The concept of an "efficient coordination zone" is introduced, for the industry to aspire to achieve, such that no placing crew would spend more than 10% of the duration of the pour in waiting for concrete and that truckmixer provision, in waiting on site and unloading, would not exceed 150% of the duration of the pour. A new model is introduced which estimates the performance of site and plant resources matching, in relation to the pour parameters of journey round trip time, RT, and the time needed to unload a truckmixer, UL. The model assumes a fleet of N truckmixers circulates between site and plant. The model may be of practical use in aiding truckmixer schedulers.

Keywords
Truckmixer, ready mixed concrete, delivery schedule, concrete batching plant, Hong Kong.

1. Introduction

In Hong Kong, it is normal for concrete to be mixed at concrete batching plants and delivered by truckmixers to sites. As each truckmixer is unloaded on site, the concrete is placed in the formwork by the site placing crew, using placing plant such as the concrete pump, crane and skip, or other, to transport the concrete between truckmixer and formwork. Ready mixed concrete is likely to be reliably of good quality than site batched concrete on average, because the ready mixed one is mixed by concrete mixing specialists and the company maintains a good reputation for concrete quality. Ready mixed concrete is welcomed in Hong Kong construction market and used almost universally.

A batching plant usually has *N* mixing bays and *M* truckmxiers to serve *S* construction sites on any particular day. The sites are at different distances from the plant and each site. Different quantities of concrete are delivered at specific times in the day. The optimal volume of concrete that a truckmixer delivers on any one day was about $27m^3$ in 2005. The values were benchmarked based on the most recent survey in Hong Kong (Tang et al. 2005). Because truckmixer drums are generally bigger today, that $27m^3$ is now likely to be an underestimate.

A plant manager plans the dispatch of the *M* truckmixers to the *S* sites, according to company strategy, taking account of pour size, site requirements, and placing methods. This scheduling task is extremely difficult if truckmixers are never to be kept waiting on site to be unloaded and placing crews are to receive a continuous unbroken supply of concrete. The plant manager assigns truckmixers to any site, in "serial" dispatch mode or "circulating" dispatch mode. In "serial" mode, deliveries are made by a series of truckmixers in general, as opposed to "circulating" mode in which a small set of truckmixers circulates between plant and site until the required number of deliveries has been made.

Circulating dispatch service to a site placing crew is an example of a balance point process, a type of construction process first identified by Halpin and Woodhead (1976). The chief characteristic, is that perfect matching of resources is only possible if the potential production rate of the central operation (placing on site in our case) is an exact *integer multiple* of the production rate of a server (the truckmixer in our case). See Section 4 below for further elaboration. The truckmixer delivery cycle in the circulating case is set out in Figure 1.

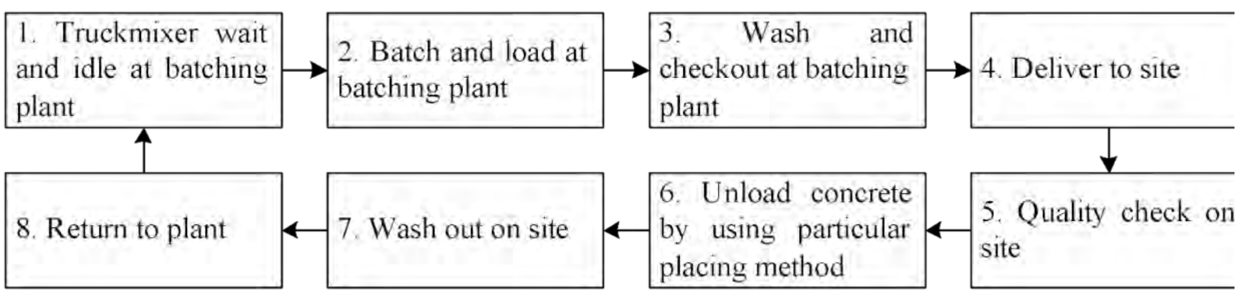

Figure 1: Truckmixer activity cycle

Once a truckmixer receives the delivery order, it moves to a plant batching bay and concrete is loaded into its drum. The truckmixer then moves to the washing and checkout area for a quality or document check, before travelling to the construction site, distant 5–25 km from the plant (Anson et al. 2002). Upon the arrival on site, the truckmixer drives to the slump and quality check area before queuing (very often), while waiting to be unloaded. Common unloading methods employ a crane and skip (tower or mobile), concrete pump, direct tip, backhoe, and others. After unloading, the truckmixer washes out on site before returning to the batching plant to await the next call. An important constraint arises from the fact that unloading should start within 1 hour 45 minutes of initial loading to avoid the risk of premature concrete setting.

The "matching" between truckmixer and crew resources achieved on sites is variable in practice and much wastage of crew and truckmixer time takes place (Anson and Wang 1998; Anson et. al. 2002; Tang et al. 2005). Too often, on the same pour, the truckmixers wait idle on site in a queue and yet, at other times, the placing crew is forced to stop work while waiting for the next delivery. Ideally, a truckmixer is unloaded as soon as it arrives on site and just as unloading of the previous truckmixer is completed.

Figures 2 and 3 are the benchmarks of the "matching" being achieved between site and truckmixer resources in Hong Kong in 1994 and 1999. The figures relate to 137 pours averaging 114 cubic metres and 118 pours averaging 69 cubic metres respectively. Perfect matching is represented by the coordinate point (0,100). Each point on the graphs represents the matching achieved on one pour. The abscissa represents crew waiting time, normalized as a percentage of the actual pour duration. The ordinate represents truckmixer time on site, both queuing and unloading, similarly normalized. The extent of the "scatter" is obvious. Only a very small proportion of pours achieve resource matching which approaches the target ideal of (0,100). This is almost certainly a measure of the difficulty of the scheduling problem, the number of economically justifiable truckmixers available in the area coupled with an inherent sensitivity of the system itself to small departures from the ideal timings.

2. Literature review

In relation to Figure 2, Anson and Wang (1994; 1998) introduced the concept of "cost efficient zone", which named as "efficient coordination zone" as marked on the figure in this research study, because the true cost effect was not determined. The plotted points within this zone represent efficient pours, where truckmixer time is not wasted excessively and waiting by the placing crew for the next delivery is similarly not excessive. All pours, for which total crew waiting is less than 10% of pour duration and truckmixers queue and unload on site for not more than 150% of pour duration, fall into this zone. The boundaries of this zone are arbitrary. It is based solely on the judgment of the researchers with reference to their studies of the concreting business and site experience. Nevertheless, in practice, it is difficult to achieve perfect matching represented by point (0,100).

For a pour of 10 deliveries taking, say, 4 hours, 10% waiting by the crew represents a wait of 2.4 minutes per delivery. This would not be seen as intolerably wasteful. The 150% "time on site" spent by the truckmixers implies roughly that when each truckmixer is halfway through being unloaded, the next truckmixer arrives on site ready to take its place. This would not seem an over-generous level of service provision by most, given that truckmixer travelling times are stochastic by nature and there can be considerable amounts of journey time variation. Just over 20% of the pours on Figure 2 fall within the "efficient coordination zone". Although arbitrary, the authors suggested that to strive for a resource matching performance within the top 20% is challenging but not daunting an aim. Accordingly, the "efficient coordination" definition for the zone as (0,100), (0,150), (10,150), (10,0) may be useful in practice. Figure 2 also shows the influence of particular unloading methods. Notably, pours unloaded by crane were generally more efficient than those unloaded by concrete pump in terms of resource coordination.

Anson et al. (2002) summarized 295 pours placed in 1999/2000, a data set derived from months of intense observation by the second author during twenty weeks spent observing the concrete delivery activities on 7 Hong Kong concrete plants (Figure 3). Only 49 of the 295 pours fell within the "efficient coordination zone". They found that 12% of large pours and 20% of small pours fell within the zone. Of course, for small pours, which need only a few deliveries, a higher proportion of all deliveries are likely to arrive in timely fashion because the early deliveries to any pour, large or small, are more likely to be dispatched close to the scheduled time. An additional factor is the high probability of an unforeseen disruption to pours of greater size and duration.

Tang et al. (2005) introduced RMCSIM (Ready Mixed Concrete SIMulation) software platform which simulated a whole day of batching plant and truckmixer activities with statistical distributions (e.g., of journey times, etc.) derived from the 1999/2000 dataset of Anson et al. (2002). As above, they found that the optimal concrete volume that a truckmixer should carry on any day is 27m^3, and that unsatisfactory concrete delivery performances are often due to site difficulties in precise planning, and other, rather than poor scheduling at the concrete plant. Lu et al. (2003) investigated how to optimize matching performance by introducing HKCONSIM, which is a computer system for the simulation modeling and analysis of the production of the Hong Kong ready mixed concrete market. Inter alia, they simulated the performance of matching between truckmixer delivery and site demands based on the dataset of Anson and Wang (1998). 17% of their simulated pours were classified as "good" matches, thereby validating HKCONSIM. The program was then used to make experimental runs allowing some recommendations on how to achieve good matching.

To add some perspective, the optimization of resource matching, as above, is only one useful objective. For example, Matsatsinis (2004) developed an optimizing model for truckmixer travel routes and timings, for a given fixed number of truckmixers serving pumped pours on a number of different sites in Greece. The timings of the pours were varied to achieve an optimum compromise between customer service and delivery costs. Naso et al. (2004, 2007) introduced a model for a multi-plant, multi-site scenario using a genetic algorithm to produce schedules minimizing truckmixer costs including those of truckmixer outsourcing and overtime. They validated the model by a case study in the Netherlands. Wang and Halpin (2004) allocated the available truckmixers to multiple projects using simulation, regression, and mathematical models in their US study. The optimum number of truckmixers was allocated to each site such that the overall pouring rate of concrete was maximized.

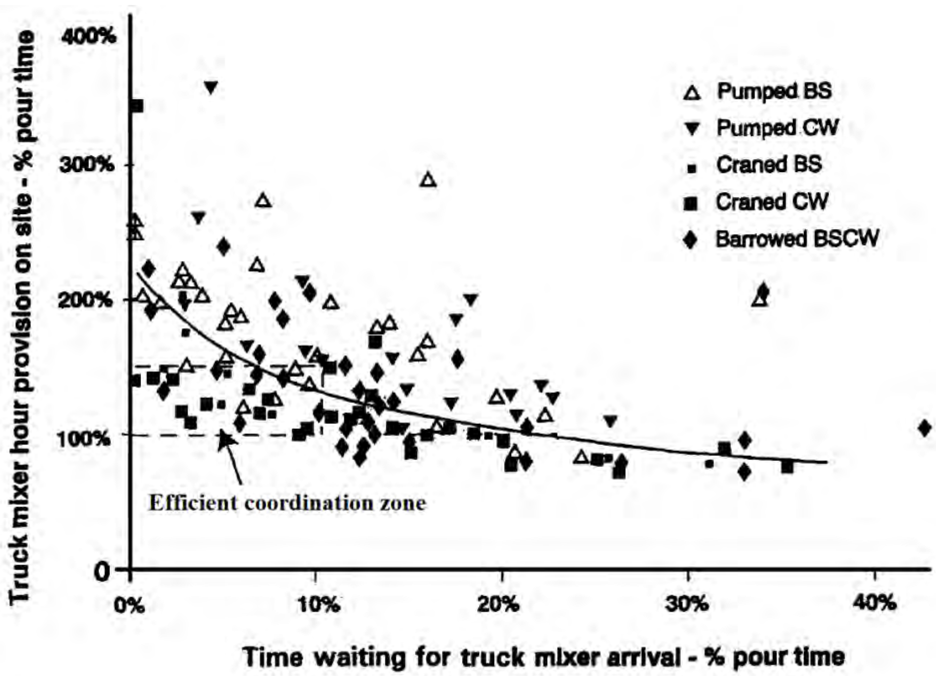

Figure 2: Truckmixer hour provision on site versus waiting for truckmixer arrival (137 pours) in 1994

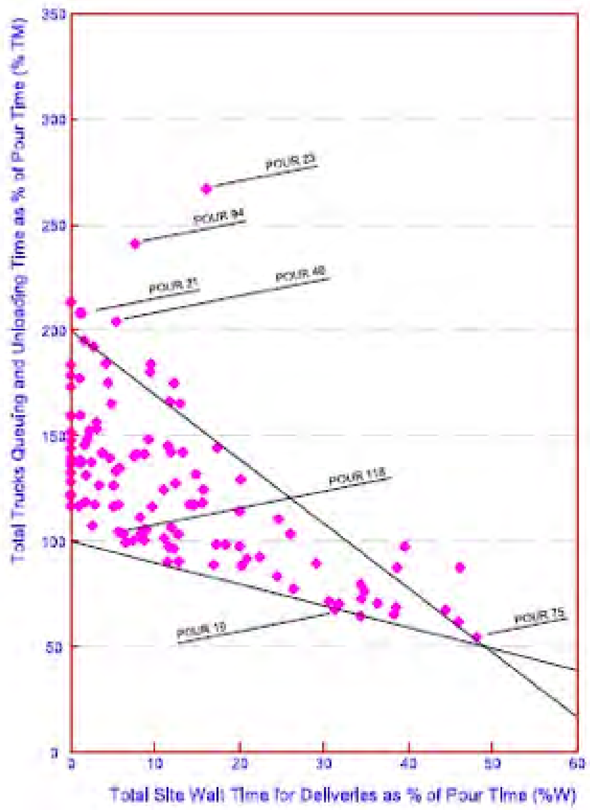

Figure 3: Matching of truckmixer queuing and unloading on site versus placing crew waiting for truckmixer deliveries (118 pours) in 1999/2000

3. Efficient coordination zone in Figure 2 and Figure 3

In both Figures 2 and 3, the lower boundary to the data distributions is governed by the equation %TM+%W=100. No point can plot below this line. It is a genuine lower bound. For points plotted on that line, no truckmixer ever has to queue and truckmixer time on site (TM) is spent wholly in unloading. But the total pour time must be TM plus the time spent by the crew in waiting for truckmixers to arrive (W), so, %TM+%W=100. Any point plotting above the lower boundary means that some queuing took place on that pour. Only for the points exactly on the line experienced no queuing.

Similarly, we can note that a number of points on Figure 3 plot exactly on the left hand boundary, %W=0, though only a few on Figure 2. Such plots represent pours where the placing crew had fresh concrete at its disposal throughout the pour.

The upper boundary is drawn arbitrarily on Figure 3 as it includes most of the points in the sample. The governing equation is %TM+3×%W=200. Thus, in general for any point in that sample (%TM+%W)>100 and (%TM+3×%W)<200. Unfortunately, if the same upper bound line were to be drawn on Figure 2, a significant number in the sample would lie above the line.

4. Efficient coordination zone for circulating dispatch

In this research study, circulating dispatch is of particular interest. As above, a set of N truckmixers circulates between plant and site until the pour is completed. The site's actual placing rate dictates the intervals between truckmixer departures from the site and hence strongly influences the intervals separating their returns to site after refilling with concrete. The result, theoretically, is better coordination as measured by %TM and %W. On the other hand, as a balance point process, we know that perfect matching is impossible unless the ratio of site production rate to truckmixer production rate is exactly an integer. If UL is the time it takes to unload a truckmixer and RT is the truckmixer round trip time (finish unload until arrive back on site), the ratio is represented by RT/UL. If N is chosen as 1+RT/UL, perfect matching occurs if RT/UL is indeed an integer. Otherwise, if N>1+RT/UL, %TM is always >100 and %W=0. If N<1+RT/UL, both %W and %TM are >0 and the two sum always to 100.

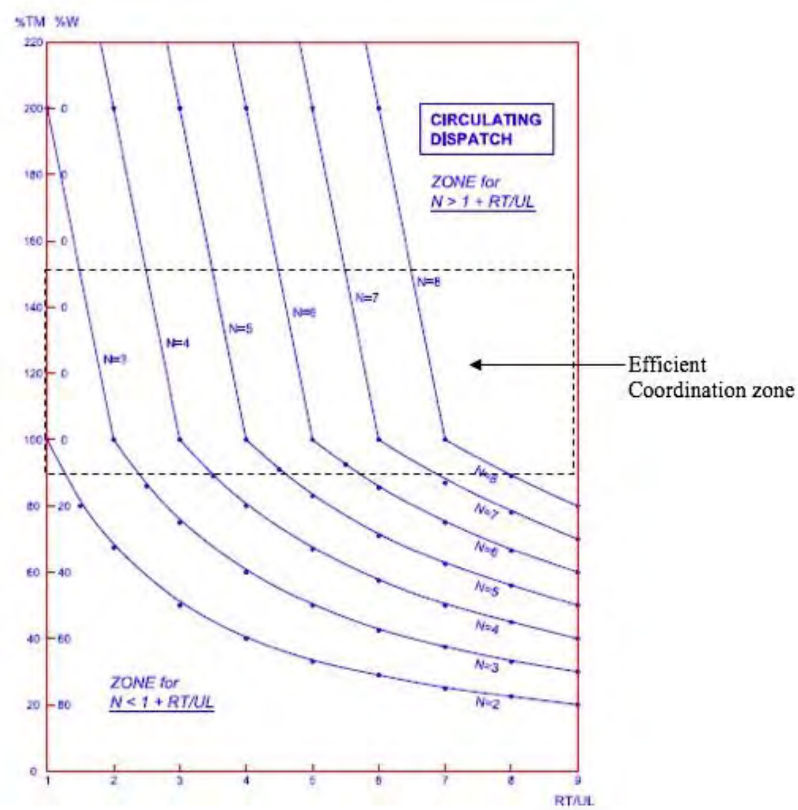

Figure 4: Circulating dispatch relationships between RT/UL, N, %W and %TM

A newly derived set of curves is plotted in Figure 4 (currently, under journal review). The curved lines are expressed by %W=100×[1–N/(RT/UL+1)], and the straight lines by %TM=100×(N–RT/UL). The diagram complements the balance point diagram of Halpin and Woodhead (1976). It augments the theory to the extent that the productivity of the server units (truckmixers) is directly provided as well as that of the central process (placing concrete in the forms). For various values of RT/UL and a given N, a graph can be plotted giving a direct read off of the resource wastage indicators %TM and %W. Figure 4 includes curves for values of N between 2 and 8.

The upper part of Figure 4, relates to N>1+RT/UL, the lower part to N<1+RT/UL. The discontinuities where the upper straight and the lower curved lines join occur when RT/UL takes integer values. These correspond with perfect matching predictions of %TM=100 and %W=0 on the left hand axis. A square is plotted on Figure 4. All points on the graphs within the "efficient coordination zone" represent efficient matching performance.

The curves are of practical use. For example, if a projected site estimates an unloading time, UL, of 25 minutes and the concrete plant manager estimates a round trip time, RT, of 50 minutes, then RT/UL is calculated as 2. As such, 3 truckmixers will be assigned to circulate with predicted perfect matching if RT and UL were to somehow remain constant for all deliveries. If, however, the site had predicted a UL of 20 minutes, 1+RT/UL would be 3.5, not an integer. The plant would assign either 4 or 3 truckmixers to circulate. If 4, there is an oversupply and %TM is 150 which can be directly read off from Figure 4. If 3, there is an undersupply and %W=14 and %TM=86 as given by Figure 4.

The curves in Figure 4 assume RT and UL both remain constant throughout the pour. This ideal scenario produces matching predictions that only lie either on the left hand axis of Figure 3 or on the lower bound line. Nevertheless, the authors proved that the plotted points do move off the boundary lines and into the "wedge" of Figure 3 by simulating the stochastic characteristic of the delivery process associated with individual truckmixers. However, it is not within the scope of this paper.

5. Conclusions

In connection with the complex problem of planning the supply of a string of concrete truckmixer deliveries to a construction site, the concept of "efficient coordination zone" is introduced. The points within the zone indicate the efficient plant and site coordinations such that the truckmixers do not wait excessively on site to be emptied and placing crews do not wait excessively for the arrival of the next delivery.

This zone is marked on Figure 2 and Figure 4 and is defined by the following two conditions:

1. The total amount of time spent by the site concreting crew in waiting for concrete deliveries is within 10% of the overall duration of the pour concerned.
2. The total amount of time spent on site by truckmixers in queuing and unloading (being emptied) is not greater than 150% of the pour duration.

These percentages are arbitrary but are potentially useful to the Hong Kong industry because a new coordination benchmark is produced. It is possible, though by no means certain, that coordination has improved over the last 20 years. In fact, the concept of the "efficient coordination zone" is important. The actual zone "dimensions" would differ from place to place. It is not likely that a practical definition of an "efficient coordination zone" would be the same for a rural region of England, say, as for the dense city of Hong Kong.

The paper introduced a analytical model, applicable only to deliveries made in circulating mode, which predicts %TM and %W values for any given ratio of RT/UL, whether an integer or not, and any value of N, the number of circulating truckmixers. RT and UL are constant throughout the pour. RT is the round trip time defined as "finish unloading on site until return to site having refilled with concrete. UL is the time it takes to unload a truckmixer. It is suggested that the managers of batching plants and construction sites might formally take account of the expected RT and UL values when planning the allocation of truckmixers to significant pours and use the model to choose a value for N likely to minimise truckmixer and placing crew time wastage such that its point will fall within the "efficient coordination zone".

Notably, there are outliers in Figure 2 and Figure 3 may have particular underlying causes other than the pour parameter and scheduling aspects discussed above. In future, a range of possible reasons for detecting and classifying the outliers will be studied by using the techniques of simulation and statistical analysis.

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Development of Web Stiffener Arrangements for Enhanced Web Crippling Strength

Michael H. Cornell
Department of Civil Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7
cornem1@mcmaster.ca

Ken S. Sivakumaran
Department of Civil Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7
siva@mcmaster.ca

Abstract

The governing capacity of a cold-formed steel flexural member depends on the relative capacities in bending, shear, web crippling, etc. and the combinations thereof. Out of these possible failure modes, perhaps the web crippling governing mode results in an inefficient (uneconomical) design of such members, since web crippling is a localized failure. The design efficiency can be improved if this failure mode can be shifted to a favourable mode of failure by increasing the web crippling capacity through the use of stiffeners. The objective of this investigation is to establish appropriate stiffener arrangement for single web cold-formed lipped channel steel sections that would enhance the web crippling capacity of such sections. The experimental investigation considered a total of 40 tests, subjected to interior two-flange (ITF), interior one-flange (IOF), end two-flange (ETF) and end one-flange (EOF) web crippling loads. The study also considered the impact of number of stiffeners and the number of screw fasteners. The first test series focused on single web elements subjected to ITF loading, where results showed that stiffened specimens gained about 25% in web crippling strength over corresponding unstiffened specimens. The same trend was found in IOF loading. The ETF tests had 106% increase in strength because the failure mode changed from web buckling to web yielding. The EOF tests had an increase in strength of 68%, and failed due to web buckling. Based on these studies, it is concluded that the most effective and economical method to increase the web crippling strength of the CFS lipped channel sections would be to attach a single stiffener to the inside of the web using three screws.

Keywords

Cold Formed Steel, Web Crippling Capacity, Experimental, Stiffeners, Number of Screws, Design Efficiency

1. Introduction

Cold-Formed Steel (CFS) structural members are widely used in the construction of low-rise buildings and houses, as a replacement to wood, masonry, etc. Such structural members are often formed to shape at room temperature from thin steel sheet (< 3mm) by machines that either roll or press the steel sheet into the desired shape. Resulting members are light weight, which provides advantages such as high strength-to-weight ratio, high stiffness-to-weight ratio, ease of shipping, each of construction, etc.

Even though the CFS sections come in different shapes (C-section, Z-section, Hat-section, I-section, Deck-section, etc.) lipped channel sections are widely used as columns (studs) and beams (joists). Depending on the span length and the loading arrangements, the capacity of the beam is governed by one of bending capacity, shear capacity, web crippling capacity, and the combination thereof. The web crippling failure potential arises when a concentrated load is applied on the flange of the channel section. Since this is a local failure, the design efficiency of the member can be improved if this failure mode can be shifted to a favorable failure mode by increasing the web crippling capacity of cold-formed steel section through the use of web stiffeners. The objective of this experimental investigation is to develop an appropriate stiffener arrangement for single web cold-formed lipped channel steel sections steel that would enhance the web crippling capacity of such sections.

2. Web Crippling of Cold-Formed Steel Channel Sections

Broadly speaking, the web crippling of cold-formed steel beams may arise due to four different loading situations. Figure 1 illustrates these situations, which are given in the North American Specification for the Design of Cold-Formed Steel Structural Members (CSA, 2016). When a load or a reaction is applied on one of the flanges at the interior flange or at the ends, then the web crippling may arise at these locations, which are identified as interior one-flange (IOF) and end one-flange (EOF), respectively. At times, the column above the floor may transfer the loads to the column (stud) below through the beam then the load is applied at both flanges. This situation may arise at the interior location or at the ends, which are identified herein as interior two-flange (ITF) and end two-flange (ETF), respectively.

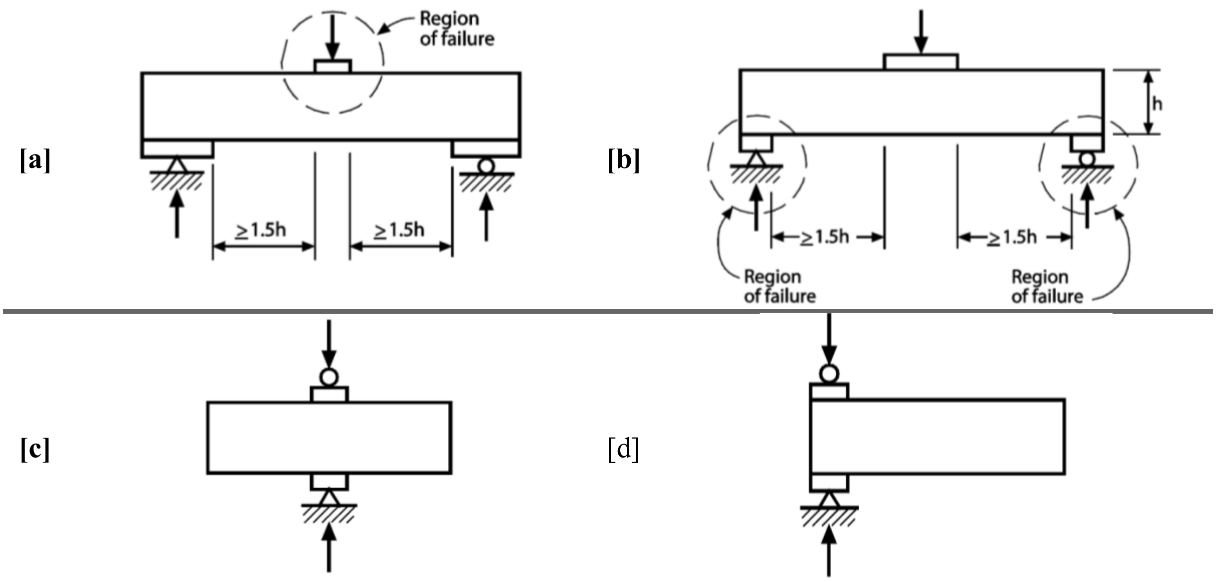


Figure 1 General Load Conditions for Web Crippling of Cold-Formed Steel Beams (CSA, 2016)
[a] Interior One-Flange [b] End One-Flange [c] Interior Two-Flange [d] End Two-Flange

The web crippling failure may be either due to web yielding, where the load bearing plate begins to crush the web causing a web failure at the web-flange intersection without significant out-of-plane deflection of the web, or due to web buckling, where the web buckles much like a slender column between the flanges. Furthermore, the web crippling resistance depends on whether the flanges are fastened to the support and on whether the flanges are stiffened (lipped). In general, a theoretical analysis for web crippling of cold-formed steel flexural members is rather complicated because it involves some or all of the following factors: (1) non-uniform stress distribution under the applied load and adjacent portions of the web, (2) elastic and inelastic stability of the web element, (3) local yielding in the immediate region of load application, (4) bending produced by eccentric load (or reaction) when it is applied on the bearing flange at a distance beyond the curved transition of the web, (5) initial out-of-plane imperfection of plate elements, (6) various edge restraints provided by beam flanges and the interaction effects between flange and web elements, and (7) inclined webs for decks and panels (CSA, 2016). For these reasons, the present design provision for web crippling is based on extensive experimental investigations conducted worldwide. The current design equation given in the North American Specification for the Design of Cold-Formed Steel Structural Members (CSA, 2016) for nominal web crippling strength of cold-formed steel section is as follows;

$$P_n = \mathrm{C}\, t^2\, F_y \sin\theta \left(1 - \mathrm{C_R}\sqrt{\frac{R}{t}}\right)\left(1 + \mathrm{C_N}\sqrt{\frac{\mathrm{N}}{t}}\right)\left(1 - \mathrm{C_h}\sqrt{\frac{h}{t}}\right) \quad [1]$$

This is a unified web crippling equation with variable coefficients and is given in a normalized format, allowing for any consistent system of measurement to be used. In this equation, P_n = Nominal web crippling strength; C = General coefficient; t = Thickness; F_y = Yield strength; θ = Angle of web inclination; C_R = Inside bend radius coefficient; R = Inside bend radius; C_N = Bearing length coefficient; N = Bearing length; C_h = Web slenderness coefficient and h = Flat dimension of web.

This experimental investigation used lipped channel sections 600S162-54, with a depth of 152 mm, flange width of 41 mm, lip stiffeners depth of 12.7 mm, thickness of 1.438 mm and inside bend radius of 1.5t, having a minimum yield strength of F_y = 345MPa. As presented in the next section, the flanges of the specimens were not fastened to the support, and the test loads were applied through a bearing plate having a width of 100mm (N). Thus, F_y = 345MPa, $\theta=90^0$, t= 1.438mm, R= 2.157mm, N=100mm, and h = 145.21mm. The coefficients C, C_R, C_N, and C_h depend on the loading condition, and the corresponding values relevant to this experimental investigation are given in Table 1. The web crippling resistances of section under consideration were also calculated for the four loading conditions and are given in Table 1.

Table 1 Web Crippling Resistance of Test Specimens as per CSA, 2016

LOADING CONDITION	C	C_R	C_N	C_H	P_n (kN)
Interior Two-Flange (ITF)	24	0.52	0.15	0.001	13.9
Interior One-Flange (IOF)	13	0.23	0.14	0.01	13.0
End Two-Flange (ETF)	13	0.32	0.05	0.04	4.8
End One-Flange(EOF)	4	0.14	0.35	0.02	7.4

3. The Experimental Setup

The web crippling tests involve exertion of an increasing concentrated load applied on the flange of the steel section. In this investigation load was applied through an unfastened 100 mm bearing plate resting on the flange of the lipped channel section, at the zone of intended failure. However, direct application of a concentrated load to a single web C-section is difficult, since it is an unsymmetrical section and is susceptible for torsional loading. The torsional effects can only be avoided by loading the specimen through its shear center. American Iron and Steel Institute publication entitled "Standard Test Method for

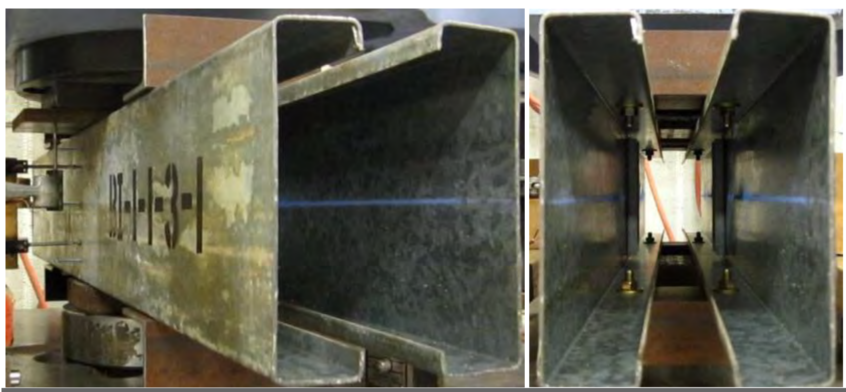
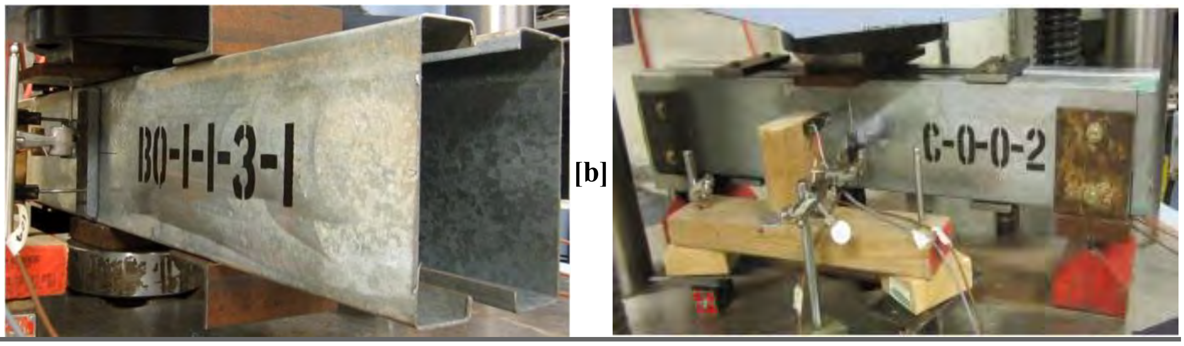


Figure 2 Test Specimen Assembly

Determining the Web Crippling Strength of Cold-Formed Steel Beams" (AISI, 2013) gives precise conditions for testing such unsymmetrical members. As shown in Figure 2, following the AISI (2013) guidelines, the actual test specimens were assembled and loaded in pairs such that the resultant load passes through the theoretical shear center of the assembly, which is the midpoint of the bearing plate. Two similar pieces of lipped channel sections were connected together using rigid steel elements (L64x64x5 mm steel angles or 64x10 mm steel plates) at the 1/4 and 3/4 points along the specimen lengths to form the test specimen assembly. Figure 2 shows the test specimen BI-1-1-3-1, which is a stiffened cross-section and is subjected to interior two-flange loading. It is assumed that each channel carries one half of the applied load.

The investigation considered four different loading arrangements as defined by the CFS Standard S136-16 (CSA, 2016), namely; Interior Two-Flange (ITF), Interior One-Flange (IOF), End Two-Flange (ETF) and End One-Flange (EOF). Each of these test groups required somewhat different setup to accommodate the position of bearing plates and support conditions to ensure that failure occurred at the desired location. Figure 3 shows the photographic images of these experimental setups corresponding to these four loading arrangements. Figure 3 (a) shows the setup for an Interior Two-Flange (ITF) test, which is perhaps the easiest setup whereby a 900mm long specimen assembly was loaded at the mid-span through two 100 mm wide bearing plates located on the mid-span top and bottom flanges. The bearing plates were aligned using a level and the specimen was centered and ensured that the centerlines of the bearing plates coincided with the centerline of the specimen. Figure 3 (b) shows the setup for an Interior One-Flange (IOF) test, where the specimen was simply supported at the ends and subjected to an increasing mid-span point load on the top-flange. In order to ensure failure under the middle load and to prevent end failure, as evident from Figure 3(b), the end supports were stiffened with 10mm steel plates. Figure 3 (c) shows the setup for an End Two-Flange (ETF) test, which is somewhat similar to the Interior Two-Flange (ITF) test, except that the loads were applied at the very end of the test specimen. As may be evident from Figure 3(c), the ETF specimens were also 900mm long, however, since the failure is limited to the very end, the same specimen was used for two tests, one test at each end. Figure 3 (d) shows the setup for an End One-Flange (EOF) test, which was a challenging setup, since the setup must cause a failure at one end while the load is applied at an interior location. In order to achieve this (i) the loading location was reinforced and the load was applied through a 10mm bracket fastened to the web, (ii) the load was applied as close as possible to the target end so as to impart a larger reaction (based on dimensions, the target end experiences 0.55P and the far end experiences 0.45P, where P is the applied load), and (iii) the far end was supported with a 40 mm overhang and the far end web was also reinforced with channels. These measures may be evident in Figure 3 (d), and as presented later, the test failures were at the target ends.

[a]



[b]

[c]  [d] 

Figure 3 Photographic Images of the Experimental Setup;
[a] Interior Two-Flange [b] Interior One-Flange [c] End Two-Flange [d] End One-Flange

Data Acquisition: An increasing point load was applied to test specimens using the universal testing machine. The machine was set to apply the load at a rate of 0.25 mm/min until visible failure of the test specimen, at which point the stroke rate was manually increased to 1.0 mm/min. The applied load was recorded by the testing machine. Except for End One-Flange (EOF) test, the test specimen web crippling load was the machine recorded load. As indicated earlier, the web crippling load for EOF tests was 0.55 times the machine recorded load. The resulting displacements of each member for the ITF, IOF and ETF test cases were collected using two lateral transducers and one vertical transducer placed on each member of the test specimen, resulting in a total of six displacement records. The second set of displacement transducers (LVDT) act as backup measurements, as well as measurements that will confirm the symmetric loading and symmetric failure of the tests. The vertical displacements used in the results given in the next section were taken as the average of the two vertical displacement readings on each side of the specimen. The End One-Flange (EOF) test specimens, however, included two more vertical displacement transducers, as well as a displacement reading of the test machine stroke, in order to establish the displacements directly at the failure location.

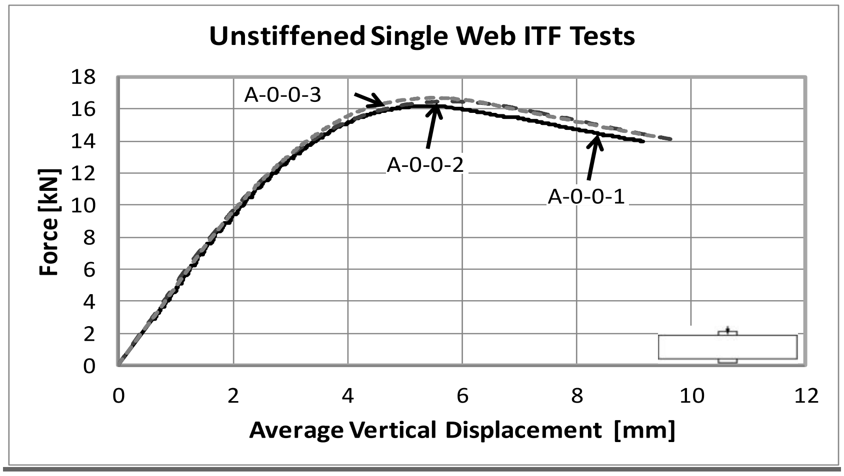


Figure 4 Load - Displacement Relations - Interior Two-Flange Tests

4. The Test Results

In order to establish the reliability and the consistency of the tests, first, three identical tests were conducted on three identical specimens. These were Interior Two-Flange (ITF) tests on regular unstiffened lipped channel sections 600S162-54, and identified herein as tests A-0-0-1, A-0-0-2 and A-0-0-3. Figure 4 shows the corresponding load-displacement relations, given for a single web, in which the load was obtained as machine load divided by 2. It is evident that three identical test specimens exhibited consistent behavior, and the corresponding ultimate loads were 16.2 kN, 16.5 kN, and 16.7 kN, respectively (Average 16.5 kN). As given in Table 1, the

Figure 5 Sample Stiffener Arrangements for Interior Two-Flange (ITF) Tests

Canadian Cold-Formed Steel Design Standard S136-16 (CSA, 2016) predicted web crippling resistance for ITF loading was 13.9 kN, which is about 15% less than the average test results.

Stiffened Webs Under Interior Two-Flange (ITF) Loading: This phase of the investigation considered different arrangements of web stiffeners fastened to the web using different screw pattern. In the interest of construction convenience and efficiency, regular bridging channels, which are widely available at cold-formed steel building construction sites, were used as web stiffeners in this investigation. These C- shaped bridging channels have a web width of 38 mm, and a lip depth of 13mm, and a thickness of 1.09mm. The length of the stiffeners was slightly less than the flat width of the test lipped channels and thus was 138mm. The investigation considered outside stiffeners and inside stiffeners, one stiffener and two stiffeners, and 2, 3, and 5 screws used to fasten each of the stiffener to the web. The corresponding specimens have been identified herein as follows; first letter indicating the stiffener location (ex. BO - B series outside stiffener and BI - B series inside stiffener), the first number indicates the number of stiffeners used in the test, the second number describes the number of columns of screws, the third number shows the number of screws in each column, and the final number refers to the iteration of the test. For example, specimen identification BI-2-2-5-1 signifies that the B series test specimen contains 2 inside stiffeners fastened to the web in two columns of screws and each column contains 5 screws. The last number indicates that this is the first test of this group.

Figure 5 shows sample photographic images of these stiffener and screw arrangements. The Figure 6 shows the representative experimental load-displacement behavior of test specimens containing different stiffener and screw arrangements. In order to facilitate comparison, the Figure 6 also shows the behavior of unstiffened web subjected to ITF loading. It is promptly evident that the outside stiffener does not enhance the web crippling resistance. Three tests considered outside stiffeners, with 2, 3, and 5 screws, respectively, and the corresponding failure loads for these specimens BO-1-1-2-1, BO-1-1-3-1 and BO-1-1-5-1 were 15.8 kN, 16.5 kN, and 16.3 kN, respectively. We observed that three or more screws improve the web crippling resistance as compared to two screws fastened stiffeners. This trend was observed even when the stiffeners were fastened to the inside face of web (between the flanges), and the corresponding results for BI-1-1-2-1, BI-1-1-3-1 and BI-1-1-5-1 were 20.1 kN, 20.8 kN, and 21.0 kN, respectively. When two parallel stiffeners were fastened on the inside with 2, 3, and 5 screws, respectively, the corresponding failure loads for these specimens BI-2-2-2-1, BI-2-2-3-1 and BI-2-2-5-1 were 19.7 kN, 19.6 kN, and 20.0 kN, respectively. We observed that two inside stiffeners do not increase the web crippling capacity as compared to one inside stiffener. These results show that one inside stiffener fastened to the web with three screws provides the optimum enhancement of the interior two flange (ITF) web crippling resistance. Therefore, the three screw fastened inside one stiffener test was repeated, and the corresponding results for three identical specimens BI-1-1-3-1, BI-1-1-3-2 and BI-1-1-3-3 were 20.8 kN, 20.5 kN, and 20.5 kN, respectively, giving an average capacity of 20.6 kN. This is about 25% increase in web crippling resistance as compared to the corresponding experimental resistance of 16.5 kN associated with the unstiffened lipped channel section subjected to interior two flange (ITF) web crippling loads.

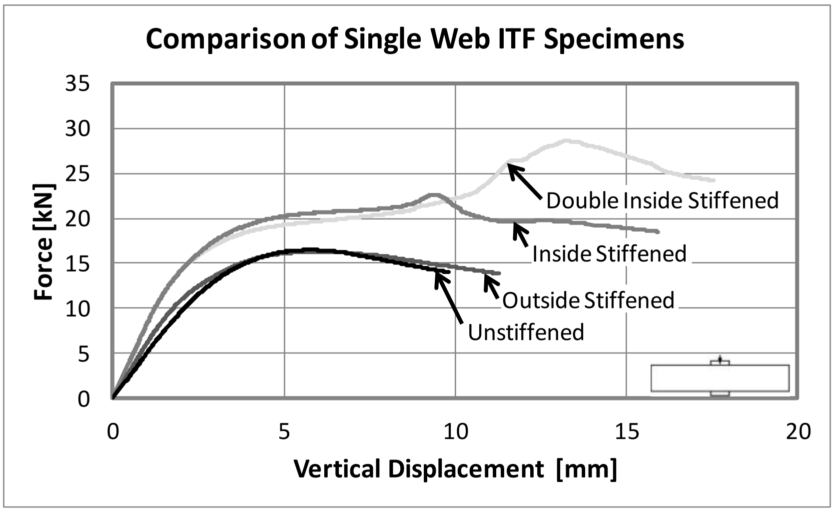


Figure 6 Representative Load - Displacement Relations - Interior Two-Flange Tests with Different Stiffener and Screw Arrangements

Interior One-Flange (IOF) Loading: This part of the investigation considered unstiffened and stiffnend webs subjected to interior one flange loading. Once again three identical tests were conducted for the unstiffened webs using lipped channel sections 600S162-54, and these tests are identified herein as tests C-0-0-1, C-0-0-2 and C-0-0-3. Even though the load-displacement relations are not given herein, the ultimate loads/single web associated with these tests were 15.0 kN, 14.7 kN, and 14.7 kN, respectively, giving an average capacity of 14.8 kN. This value may be compared to the design values given in Table 1, and accordingly, the experimental results are 14% higher than the Canadian Cold-Formed Steel Design Standard S136-16 (CSA, 2016) predicted IOF web crippling resistance, which was 13.0 kN. Based on earlier test observations, this series of tests focused on enhancement of interior one-flange web crippling resistance through an inside stiffener. One stiffener was centered and screw fastened to the lipped channel section, right under the loading bearing plate. Three tests considered stiffeners, with 2, 3, and 5 screws, respectively, and the corresponding failure loads for these specimens DI-1-1-2-1, DI-1-1-

3-1 and DI-1-1-5-1 were 17.6 kN, 18.5 kN, and 18.0 kN, respectively. Once again, three screws fastening arrangement gives optimum results. The three screws fastened inside one stiffener test was repeated, and the corresponding results for three identical specimens DI-1-1-3-1, DI-1-1-3-2 and DI-1-1-3-3 were 18.5 kN, 18.0 kN, and 18.5 kN, respectively, giving an average capacity of 18.3 kN, which is 25% higher than the corresponding experimental resistance of 14.8 kN associated with the unstiffened lipped channel section subjected to interior one flange (IOF) web crippling loads.

End Two-Flange (ETF) Loading: The next phase of the investigation focused on enhancement of exterior two flange loading web crippling resistance using interior stiffeners fastened along the centerline of the end bearing plates. The bench mark web crippling resistance of unstiffened section under this loading was 7.2 kN, which was based on three identical tests. The Canadian Cold-Formed Steel Design Standard S136-16 (CSA, 2016) predicted ETF web crippling resistance which was 4.8 kN, which is obviously, 66% of the experimental resistance. Three identical specimens having a single interior stiffener screw fastened at three locations and identified as FI-1-1-3-1, FI-1-1-3-2 and FI-1-1-3-3 were 15.0 kN, 14.8 kN, and 14.8 kN, respectively, giving an average capacity of 14.9 kN, which is more than double the experimental web crippling resistance associated with the unstiffened lipped channel section subjected to End Two Flange (ETF) web crippling loads. Figure 7 shows representative load displacement relations associated with these tests. Once again, it is evident that interior stiffener with three screws provide the best improvement in the web crippling resistance.

End One-Flange (EOF) Loading: The final phase of this investigation considered the exterior one flange loading web crippling resistance. As presented in the previous section, the load was applied off-center, and the loading point and the far end were reinforced to prevent failure at these locations. This setup ensured that the failure occurs at the near end. Based on the geometry and equilibrium, the near end experiences 0.55 P, where P is the machine load. Since, the test specimen consists of two webs the load resisted by each web can be taken as 0.275P, which is used in the following discussions.

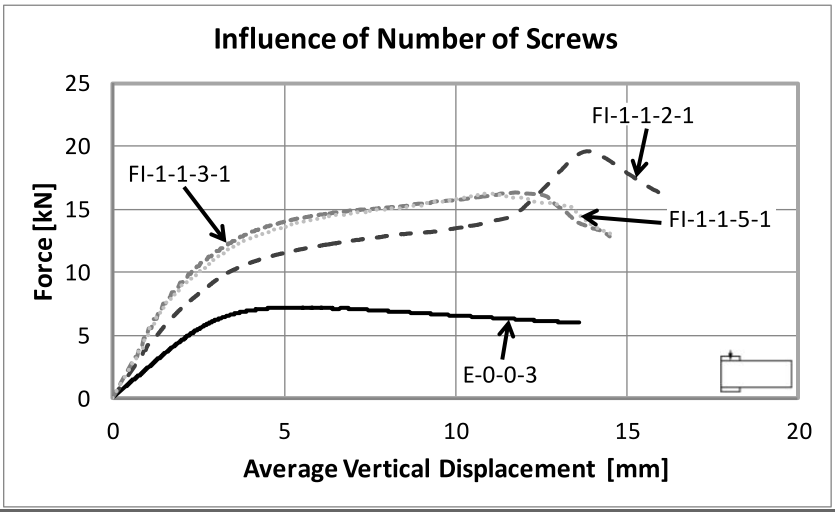


Figure 7 Representative Load - Displacement Relations - End Two-Flange Tests with Interior Stiffener and Different Screw Arrangements

Similarly to the other tests, first, three identical End One Flange (EOF) tests were conducted on three identical specimens fabricated from regular lipped channel sections 600S162-54. These specimens are identified herein as tests G-0-0-1, G-0-0-2 and G-0-0-3, and the corresponding web crippling capacities were 7.9 kN, 7.9 kN, and 8.1 kN, respectively, giving an average capacity of 8.0 kN. This value may be compared to the design values given in Table 1, and accordingly, the experimental results are 8% higher than the Canadian Cold-Formed Steel

Design Standard S136-16 (CSA, 2016) predicted EOF web crippling resistance which was 7.4kN. As in the previous test series, two, three and five screws fastening arrangements were investigated, however, only the unstiffened specimens and inside stiffened specimens with three screws were verified by three identical tests. Figure 8 shows the representative force-displacement relations. Note that the force shown in this figure is associated with the force experienced by one of the flanges at the target end (end that failed), which was established from machine loading and basic mechanics as 0.275P. It can be observed that the impact of various screw arrangements is negligible. The specimens HI-1-1-3-1, HI-1-1-3-2 and HI-1-1-3-3, which are the three identical specimens having a single interior stiffener screw fastened at three locations and subjected to end one flange loading, carried loads of 13.3 kN, 13.4 kN, and 13.9 kN, respectively, prior to failure. Thus, the experimental average stiffened EOF web crippling resistance is 13.5 kN, which is 69% more than the experimental web crippling resistance associated with the unstiffened lipped channel section subjected to End One Flange (EOF) web crippling loads.

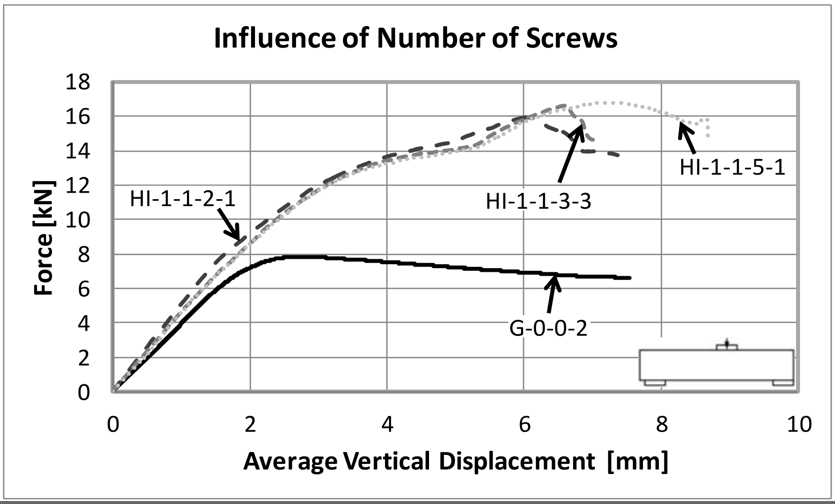


Figure 8 Representative Load - Displacement Relations - End One-Flange Tests with Interior Stiffener and Different Screw Arrangements

5. Concluding Remarks

Cold-Formed Steel (CFS) structural beams (joists) are widely used in the construction of low-rise buildings and houses. Such beams may fail in many different modes, however, the web crippling failure is an inefficient governing mode, since web crippling is a localized failure. The objective of this experimental investigation was to develop an appropriate stiffener arrangement for single web cold-formed lipped channel steel sections steel that would enhance the web crippling capacity of such sections. The experimental investigation considered a total of 40 tests, subjected to interior two-flange (ITF), interior one-flange (IOF), end two-flange (ETF) and end one-flange (EOF) web crippling loads. The investigation also established the impact of number of stiffeners and the number of screw fasteners. The following conclusions were made based on this experimental investigation; (i) The outside stiffener does not enhance the web crippling resistance, as compared to an inside stiffener. (ii) Two inside stiffeners do not increase the web crippling capacity as compared to one inside stiffener. (iii) One inside stiffener fastened with three screws provides an optimum enhancement of web crippling resistance as compared to two screws and five screws. (iv) Even though attachment of a single stiffener to the inside of the web using three screws provided different amount of web crippling strength gains based on the loading situation, such a reinforcement increases the web crippling capacity of the cold-formed steel section under consideration by at least 25%. Additional tests on sections with different dimensions are required prior to prescribing a universal recommendation.

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Evaluation of Different Building Structural Systems: The Case of Turkey

Esra Bostancioglu
Assoc.Prof.Dr., Department of Architecture, Istanbul Kultur University, Istanbul, Turkey
esrabostancioglu@hotmail.com

Abstract
A building structural system is evaluated by using several parameters such as cost, construction time, fire resistance, lifetime, maintenance and repair frequency and environmental impacts. This study aims to evaluate buildings constructed with different structures in Turkey. Existing building stock in Turkey is assessed in terms of structures and number of stories. For the economic evaluation of the structures, a two-storied residential project is selected as an example. For the assessment of construction cost, structural cost and the other cost components for different structures, the selected project is designed with three different structures. Selected structures are; masonry, reinforced concrete framed and wood framed structures. These structures are evaluated in terms of economic features as well as other features for providing investors with tips on how to choose the structure in future. The current situation of structures in Turkey is also examined.

Keywords
Building Structures, Masonry Structure, Reinforced Concrete Framed Structure, Wood Framed Structure, Construction Cost, Structural Cost.

1. Introduction

The assessment of a structural system involves several parameters such as cost, construction time, fire resistance, lifetime, maintenance and repair frequency, and environmental impacts. Different structures have different characteristics. Some cannot be used in multi-storey buildings because of their load-bearing capacities, some take shorter time to construct and some have lesser impacts on the environment. Hence, they can be evaluated from many perspectives. Cost is one of the most important parameters in evaluating a structure. It can be said that the main objective for each project is economic efficiency. Economic efficiency means the benefit of a designed building is larger than the cost it involves. Building production in Turkey makes up a large share of the construction sector and national investments, hence it is vital to meet the need for building through the most economical way.

This study aims to evaluate buildings constructed with different structures in Turkey. Some structures cannot be used in multi-storey buildings, hence buildings in Turkey are primarily assessed in terms of structures and numbers of stories. Then, an assessment is made of construction costs, structural costs and other cost components for a selected 2-storey residential building if it is constructed by using three different structures. In addition, these three different structures are evaluated in terms of other characteristics, providing investors with information about various characteristics of the structures they may choose, to help them to make the right decisions. After three different structures are assessed, the current situation of structures in Turkey is examined.

2. Building Structures

Masonry structures refer to systems where numerous and relatively small building materials such as stone, brick, block, wood, adobe and gasbeton are placed one on top of other to form a load-bearing wall with their own weight or with a binder / adhesive material. Load-bearing walls formed transfer the loads placed on them to the ground via the foundation. The foundation has to be continuous where there is the load-bearing wall. In masonry systems, openings for doors and windows can be created on load-bearing partitions and external walls as much as permitted by regulations for given locations; walls are connected with horizontal and vertical elements called beams based on tensile strength.

Reinforced concrete framed structures refer to systems in which dynamic and static loads exerted on structures are born by supporting elements such as columns, beams and vertical loads are transferred to the foundation system via columns. All walls only carry their own load and transfer their load to the slab whatever their floor, whilst the slabs convey the loads exerted on them to the columns through the beams or directly. In this structure, walls do not bear loads (except shear walls), hence they can be replaced or removed whatever the floor, thus providing flexibility in the use of spaces. Reinforced concrete framed structures can be constructed with different construction technologies, such as cast-in place and prefabricated, allowing the construction of multi-storey buildings. In reinforced concrete framed structures, elements of the structure take a small place in the slab, providing flexibility in interior space use and facade design.

One dimensional wood component assumes the role of structure in wood framed structures. The gaps between the studs are filled with a component such as adobe, brick, gasbeton. Plaster can be applied on the wall surfaces or the outward facing surfaces of the laths and studs may be covered to provide desired insulation and protection against external factors.

Researchers compared different building structures in literature. Hemström, Mahapatra and Gustavsson used a web-based questionnaire to assess Swedish architects' perceptions, attitudes and interest towards steel, concrete and wood frames in multi-storey buildings (n = 412). Results indicate that the responding architects find concrete the most suitable frame material in buildings of 3–8 storeys, mainly because of the performance of concrete with regards to the engineering aspects (e.g. stability and fire safety) that were considered important in the choice of frame material. Although wood is considered the least suitable frame material, the overall attitude towards, and interest in, using wood is positive and related to the perceived environmental benefits of wood. This may derive from an increased discussion of and information about the environmental impact of buildings. Wood may be perceived as new and innovative while not considered as adequately proven as steel and concrete with regards to engineering aspects (Hemström, et.al., 2011).

Börjesson and Gustavsson calculated primary energy use and carbon dioxide (CO_2) and methane (CH_4) emissions from the construction of a multi-storey building, with either a wood or a concrete frame, from life-cycle and forest land-use perspectives. The primary energy input (mainly fossil fuels) in the production of building materials was found to be about 60-80% higher when concrete frames were considered instead of wood frames. The net greenhouse gas (GHG) balance for wood materials will depend strongly on how the wood is handled after demolition of the building. The net GHG balance will be slightly positive if all the demolition wood is used to replace fossil fuels, slightly negative if part of the demolition wood is re-used, and clearly positive if all wood is deposited in landfills, due to the production of CH_4. If concrete frames are used, the net GHG emissions will be about those when demolition wood from the wood-framed building is deposited in landfills and no biogas is collected. If forest biomass is used instead of fossil fuels, the net area of forest land required to supply both raw material and energy for the production of building materials, will be about twice as high when wood frames are used instead of concrete frames. However, the GHG mitigation efficiency, expressed as CO_2 equivalents per unit area of forest land, will be 2-3 times higher when wood frames are used if excess wood waste and logging residues are used to replace fossil fuels. The excess forest in the concrete frame alternative is used to replace fossil fuels, but if this forest is used for carbon storage, the mitigation efficiency will be higher for the first forest rotation period (100 yr), but lower for the following rotation periods (Börjesson and Gustavsson, 2000). Xing, Xu and Jun compared the environmental effects of two different building structures, steel and concrete. The results show that the steel framed building is superior to the concrete framed building on the following two indexes, the life cycle energy consumption and environmental emissions of building materials. It is found that the life cycle energy consumption of building materials per area in the steel framed building is 24.9% as that in the concrete framed building, whereas, on use phase, the energy consumption and emissions of steel framed building are both larger than those of concrete framed building. As a result, lower energy consumption and environmental emissions are achieved by the concrete framed building compared with the steel framed building on the whole life cycle of building (Xing et.al., 2007).

3. Review of Existing Building Structures in Turkey (Case Study)

The assessment of existing buildings in Turkey in terms of structures, numbers of buildings provided by the Turkish Statistical Institute based on occupancy permits have been used in the review. (https://biruni.tuik.gov.tr/yapiizin). By the year 2016, the distribution of the existing buildings in Turkey by their structures shows that reinforced concrete framed structures are the most commonly preferred structures with 93.24%. As shown in the Table 1 and Figure 1, out of the existing structures, the masonry structures make up 2.76%, steel framed structures 1.77%, prefabricated structures 1.43%, composite structures 0.62% and wood framed structures 0.18%. The masonry structures, the wood framed structures and the prefabricated structures cannot be used in multi-storey buildings in terms of load bearing properties. Existing statistics show that steel framed structures and composite structures are not very common in multi-storey buildings in Turkey. As of 2016, the distribution of existing buildings in Turkey in terms of number of stories is as follows: 15.85% are single storey, 17.65% 2-storey, 16.35% 3-storey, 12.77% 4-storey, 15.02% 5-storey, 11.22% 6-storey, 4.69% 7-storey, 1.47% 8-storey, 1.24% 9-storey and 3.73% are 10-storey or more. (Table 1, Figure 2). 45.48% of existing structures are 1 to 3 storey buildings. In order to compare different structures in the study, a residential building has been chosen as an example. The building to be evaluated has been designed as a two-storied structure, since it is the most preferred number of stories in the existing buildings and it can be constructed with all the alternative structures. As of 2016, the distribution of the existing two-storied buildings by structures shows that 2-storey buildings are indeed the most commonly preferred type. In 2-storey structures, the reinforced concrete framed structures are the most common structures with 89.53%. In the existing 2-storey buildings, the masonry structures make up 6.50%, steel framed structures 1.31%, prefabricated structures 1.63%, composite structures 0.66% and wood framed structures 0.37% (Figure 3). When we examine the distribution of the structures in the existing 2-storey buildings between 2011 and 2016, reinforced concrete framed structures seem to be dominant (Table 2, Figure 4). The distribution does not change much in 2016.

Table 1: Number of the different structures according to their number of stories in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

	1-storey	2-storey	3-storey	4-storey	5-storey	6-storey	7-storey	8-storey	9-storey	10+ -storey
masonry	1,497	1,361	410	6	3					
steel framed	1,731	275	49	13	14	6	1	3		7
wood framed	94	77	40							
reinforced concrete framed	13,902	18,759	18,745	15,088	17,760	13,263	5,550	1,744	1,470	4,387
composite	294	139	90	51	51	52	19	2	4	36
prefabricated	1,289	341	68							
total	**18,807**	**20,952**	**19,402**	**15,158**	**17,828**	**13,321**	**5,570**	**1,749**	**1,474**	**4,430**

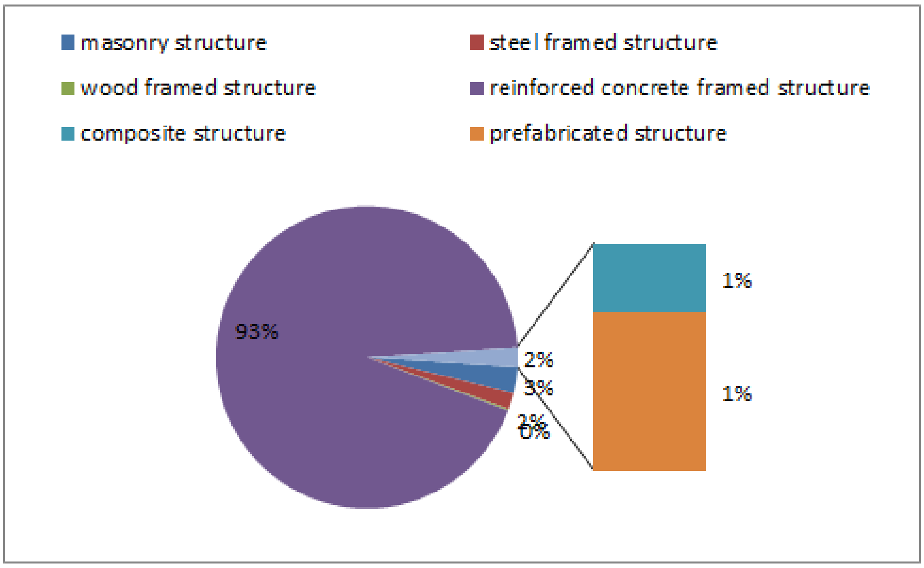


Figure 1: Distribution of existing structures in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

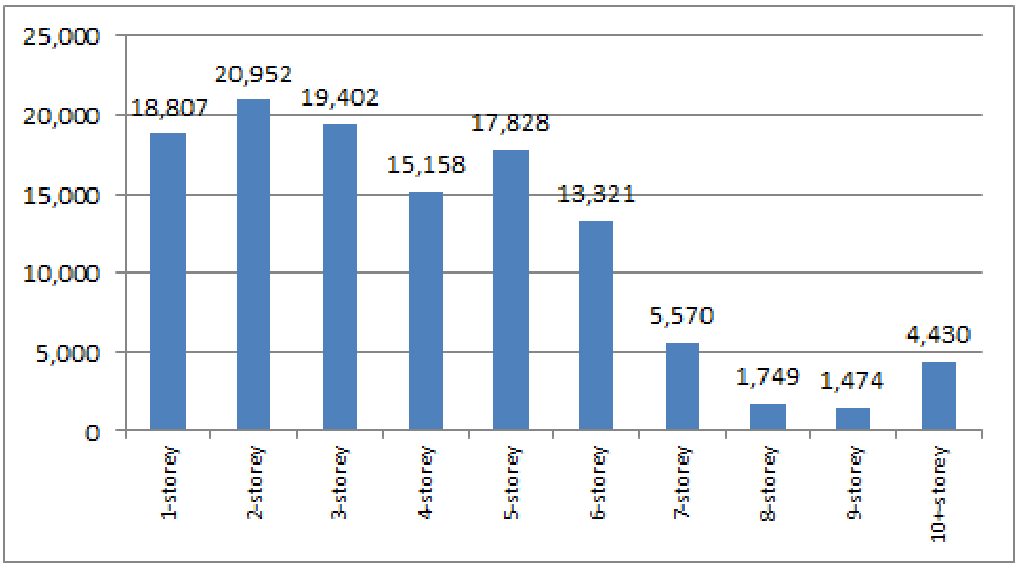


Figure 2: Distribution of existing buildings according to their number of stories in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

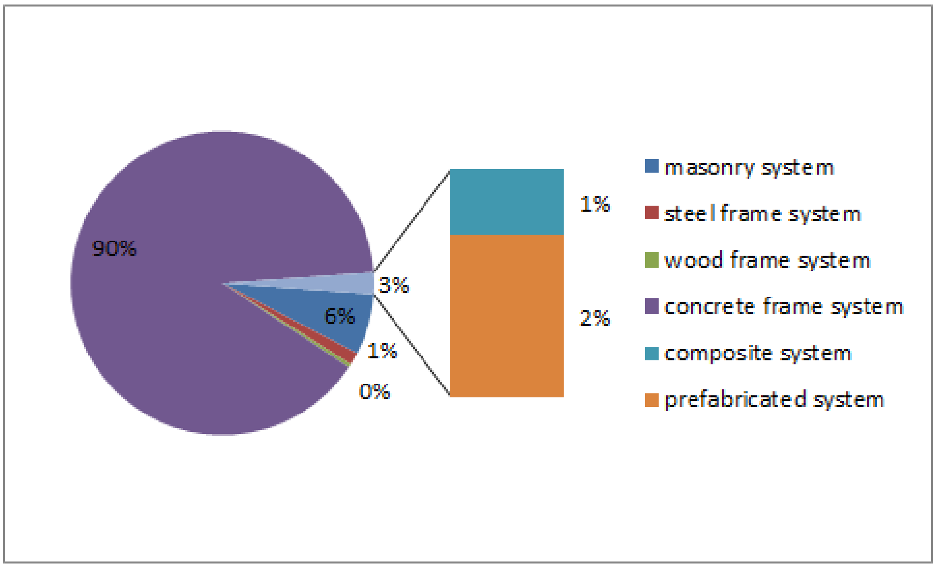


Figure 3: Distribution of existing 2-storey structures in Turkey (2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

Table 2: Number of the different structures in Turkey between 2011 and 2016
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

	2011	2012	2013	2014	2015	2016
masonry structure	2,279	2,117	2,484	2,115	1,659	1,361
steel framed structure	218	252	287	308	262	275
wood framed structure	102	91	88	150	54	77
reinforced concrete framed structure	20,910	20,155	22,076	23,002	18,002	18,759
composite structure	95	126	245	217	165	139
prefabricated structure	191	205	303	353	493	341
total	**23,795**	**22,946**	**25,483**	**26,345**	**20,635**	**20,952**

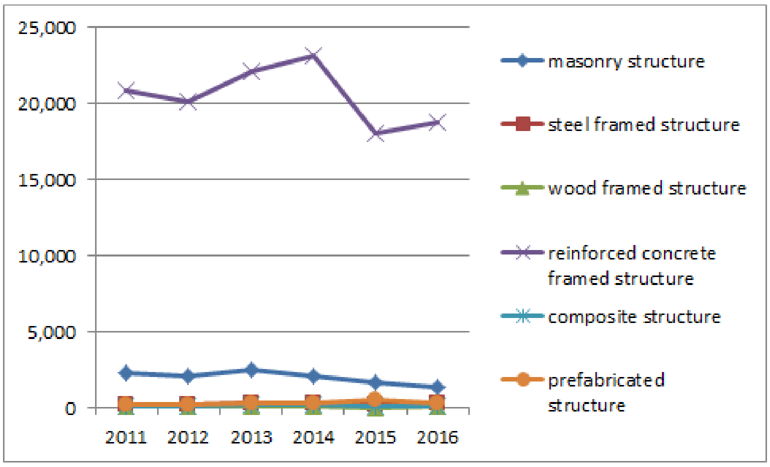


Figure 4: Distribution of existing 2-storey structures in Turkey (2011-2016)
Source: Turkish Statistical Institute (https://biruni.tuik.gov.tr/yapiizin)

4. Economic Evaluation of Building Structures (Case Study)

The study assesses different structures from an economic perspective, it examines the economic differences that would emerge if a 2-storey residential building is constructed with different structures. The selected structure is a 2-storey residential building with four sides open with a total floor area of 148 m^2. In terms of the structures, it has been considered that the 2-storey residential building may be constructed with masonry structure, reinforced concrete framed structure and wood framed structure. Only the characteristics relating to the structure have changed in these buildings, with all the other variables being kept the same. The three residential buildings have been considered to have the same plan characteristics, gross area and qualities.

4.1. Methodology

Projects for each residential project with different structures have been prepared. Necessary measurements have been made on the prepared projects, with quantity surveys determining the quantity of each work item. The quantities determined have been multiplied by the unit prices of the Ministry of Environment and Urbanization for the year 2017, allowing for a calculation and assessment of construction and structural costs (https://birimfiyat.csb.gov.tr).

In the second stage; by using the bill of quantities used in the calculation of the construction costs of the residential buildings to be constructed with three different structures; costs related to infrastructure, structure and finishes works which are the basis of CI / SfB Construction Information classification and indexing system adopted in European countries as well as their shares in construction costs have been determined and evaluated.

Construction information classification systems can be used to support this information management process. The classification structure in a construction information classification system defines concept hierarchies that can be used for document classification, providing a common framework for document organization and management among project organizations. These classification frameworks can be embedded in inter-organizational information systems, like project websites, project management software, and document management systems. Examples of CICSs include: the CSI MasterFormat, CSI UniFormat, CI/SfB, Uniclass, and the Overall Construction Classification System (Caldas, and Soibelman, 2003). CI/SfB is the Construction Index/ Samarbetskommitten for Byggnadsfragor, a Scandinavian classification system for libraries set up in 1959 and intended for the construction industry. This system has been used worldwide for technical and trade literature in the construction sector. In recent years it has been gradually superseded by Uniclass, which has a much wider coverage and is able to encompass new building types and concepts involving energy and environmental issues. However, many architectural libraries are still organised according to the CI/SfB system. An index of subjects organised by CI/SfB assists with company and/or product selection. Main groups in element category of CI/SfB are substructure, structure, finishes, fittings, external works. Classification of building system is seen in Table 3.

Table 3: Classification of building system (https://www.ribaproductselector.com)

Substructure	Structure	Finishes
(11)Ground works	(21)External walls	(41)Wall finishes: external
(13)Floor beds, ground floors, basements	(22)Internal walls, partitions	(42)Wall finishes: internal
(16)Foundations, retaining walls	(23)Floors, including beams	(43)P Floor finishes: jointless
(17)Pile foundations	(24)Stairs	(43)S Floor finishes: rigid tiles, slabs, mosaic
	(27)Roofs, including beams	(43)T Floor finishes: flexible sheets, including rubber, plastics
	(28)Building frames	(43)T Floor finishes: carpets
	(29)Patent glazing	(43)X Floor finishes: wood systems
	(31)External & entrance doors/screens	(43)Y Floor finishes: finishes, accessories
	(31.4)Windows	(44) Stair finishes
	(31.49)Windows, parts, accessories	(45) Ceiling finishes

(31.5)Doors: industrial (31.5)Doors: general (31.59)Doors: parts, accessories (31.9)Lintels, sills, weatherbars, other window/door parts (32)Room dividers, internal grilles etc. (33)Access floors (34)Balustrades (35)Suspended ceilings (37)Rooflights	(47) Roof finishes

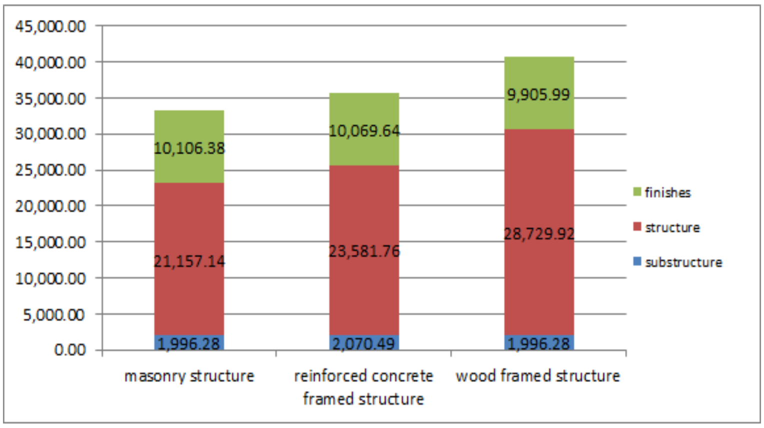
This study has been based on this classification, but since the study only covers the construction costs, the cost assessments considered the infrastructure, structure, and finishes.

4.2. Findings

As can be seen from Table 4 and Figure 5, the masonry structure seems to be the most economical alternative according to the assessment of construction costs of the residential buildings to be built with three different structures. It is observed that the construction cost of the reinforced concrete framed structure is 7.40% higher than the masonry structure and 22.17% more than the wood framed structure. As all the properties of the selected buildings are assumed to be the same except for the structures, the analysis of Table 3 shows that the variations in the construction cost arise from the structural cost. Figure 5 assesses infrastructure, structure and finishes costs and the share of within the total construction cost. In the masonry structure; infrastructure makes up 6.00% of the construction cost, structure 63.31% and finishes cost 30.39% of the total costs. In the reinforced concrete framed structure; 5.80% of the construction cost belongs to infrastructure, 66.01% to structure and 28.19% to finishes costs. In wood framed structure; 4.91% of the construction costs belong to infrastructure, 70.71% to structure and 24.38% to finishes costs. As can be seen, the structure costs have the largest share in construction costs in all the three structures. In the wood framed structure, the share of the structure cost within total construction cost is higher than the other systems.

Table 4: Evaluation of construction costs for different structures

	substructure cost ($)	structure cost ($)	finishes cost ($)	(total) construction cost ($)	relative construction cost
masonry structure	1,996.28	21,157.14	10,106.38	33,259.80	100.00
concrete framed structure	2,070.49	23,581.76	10,069.54	35,721.89	107.40
wood framed structure	1,996.28	28,729.92	9,905.99	40,632.19	122.17



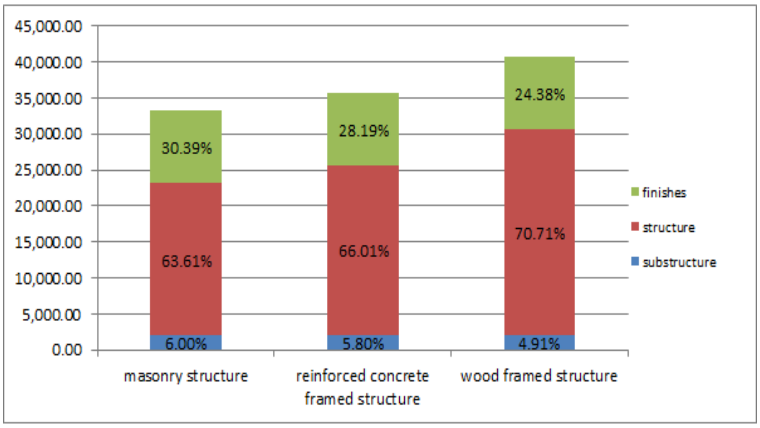


Figure 5: The costs for infrastructure, structure, finishes and the share of within the total construction costs

Structural costs are compared in Table 5 and Figure 6. The lowest structural cost belongs to the masonry structure. The structural cost of the reinforced concrete framed structure is 11.46% higher than the masonry structure, with the wood framed structure 35.79% higher. Out of the three structures, the wood framed structure has the highest structural cost.

Table 5: Evaluation of structural costs for different structures

	structure cost ($)	relative structure cost
masonry structure	21,157.14	100.00
reinforced concrete framed structure	23,581.76	111.46
wood framed structure	28,729.92	135.79

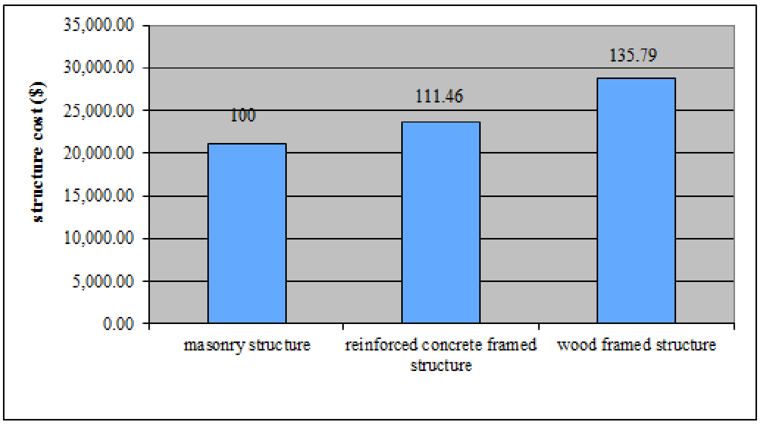


Figure 6: Structural costs for different structures

5. Results and Conclusion

The economic assessment made for buildings built with three different structures in Turkish context suggests that the most economical structure for the selected 2-storey residential project is the masonry structure. However, the construction costs of reinforced concrete framed and masonry structures are similar to each other. The construction cost of wood framed structure is 22.17% more than the masonry structure and 13.75% more than the reinforced concrete framed structure. In the comparative exercise, since all the variables of the buildings have been taken the same except the structure; it has been observed that the variations in the construction cost result from the structural cost. Therefore, in terms of the evaluation of the structural costs; the highest structural cost is observed in the wood framed structure and the lowest structural cost is observed in the masonry structure.

The assessment of buildings with these three different structures shows that the masonry structure has some disadvantages compared to the other structures, in that it is heavier than the other structures, it has some problems in terms of creating openings as compared to the reinforced concrete framed structure, it does not allow for transparent façades and multi-storey buildings. At the same time, the walls are bearing systems, so wall thicknesses increase. The elements of the structure occupy more space and the useful space decreases in a building with the same floor area. Reinforced concrete framed structure is lighter compared to masonry structure and allows for multi-storey construction. It does not have any limitations in creating openings for doors and windows, it allows for creating any opening on internal and external walls. The walls may be removed completely and it allows more flexible design. On the other hand, although wood framed structure is the most expensive alternative, it is built with a natural material, so its impact on the environment is less than that of the other two structures. It can be constructed in a shorter time, and the wood has much better thermal insulation properties than the reinforced concrete. However, the fire resistance is less than the masonry and reinforced concrete framed structures and wood framed structure requires more frequent maintenance and repair. Although the destruction of masonry and reinforced concrete framed structures result in a rubble pile, recycling is possible in the destruction of the wood framed structures.

The assessment on the distribution of the existing 2-storey buildings in Turkey by the type of the structures shows that reinforced concrete framed structures are the most commonly preferred structures with 89.63% to 86.53% between the years 2011 to 2016. The masonry structures make up 6.50% to 9.75% and their share has gradually diminished up to date. The wood framed structures make up 0.26% to 0.57%. It is thought-provoking to see that the masonry structures are preferred too little although they are more economical than the reinforced concrete framed structures; the same applies to the wood framed structures, which are used too little although they have some advantages in that they use a natural material, they have lesser impact on the environment and can be recycled. In the future, it is predicted that these two structures, which are superior to the reinforced concrete framed structures in some respects, would be preferred more in building production in Turkey.

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Stochastic Frontier Analysis of Water Supply Utility of Urban Cities in Bosnia-Herzegovina

Assistant Professor Ivana Domljan, PhD
University of Mostar, Mostar, Bosnia and Herzegovina
ivana.domljan@tel.net.ba

Abstract

Municipalities in Bosnia and Herzegovina (B-H) are responsible for both providing water supply services and maintaining and operating their infrastructure. The municipally owned companies, currently the only ones providing municipal water services, are in a perpetual crisis due to several reasons – the major being the inherited model from the communist period.
The characteristics of the inherited model are prices not covering operating costs, maintenance and investments, low quality standards, and water facilities not protected from potential hazards.

Despite the severe scarcity of data for B-H water sector, given the available data we developed a SFA model, a useful tool in assessing the relative efficiencies of water supply companies as well as for the selection of most critical companies for introducing public-private partnership (PPP) for improving the situation regarding efficiency.

Among the first steps in the efficiency analysis of B-H water operators, this research could serve as a benchmark against which future analysis of water utilities can be measured. Additionally, it provides policy makers with evidence on the water utility efficiency with the aim of focusing on the improvements in managing companies and on rebuilding the water sector infrastructure, beginning with the most inefficient ones to minimize huge water losses.

Keywords

Water, Efficiency, public-private partnership, Bosnia-Herzegovina

1. Introduction

Estimates of the Office of the High Representative and EU Special Representative to B-H reveal that the total investment sum in the water supply and sanitation sector to bring the B-H water services in line with the service level of EU Member Countries amount to around 6.9 billion USD for achieving full compliance with all relevant EU standards through the year 2030.
On its EU way, B-H will be obliged to follow the Directive 2000/60/EC stating that all costs incurred by water utility should be covered by revenues and estimates of relevant investment including forecasts of such investments. This principle of cost recovery for water supply is not understood adequately in B-H and is not included into the legislation for local public authorities.
The purpose of this paper is to highlight the low efficiency of the system and propose a strategy of achieving better results based on measuring the relative efficiency of B-H water utilities.

This paper is intended to deal with the issue of how to assess and improve the efficiency of the B-H water companies. Additionally, it will provide policy-makers and financial institutions with comparable quantitative evidence on the effectiveness of water utilities with the aim of rebuilding the water sector infrastructure components, beginning with the most inefficient municipalities in order to minimize huge water losses.

The paper is organized as follows: the first part is introductory, intended to inform how far B-H is from the fulfilment of the EU water directive. The second part presents the institutional and regulatory background and simple ratio analysis. The third part deals with statistical modelling with the emphasis on SFA. The fourth part applies SFA to available data from the B-H water industry and discusses some striking differences in their efficiency results. Summary and concluding comments are provided in the fifth part.

2. Institutional and regulatory background

In B-H, responsibility for water service provision is decentralised and rests with municipalities. There are about 130 municipal water companies in B-H serving the needs of a population of 3.5 million.

The municipally owned water companies operate as formally autonomous organisations, separated administratively and financially from the municipal government. However, devolution of responsibility to company level is substantially very weak. They are not empowered and enabled to function as efficient service providers. By being obliged on overemployment, artificially depressed tariffs, following political rather than economic criteria in signing up contracts and undertaking investments etc. they spiral costs, accrue losses and weaken quality of service.

Due to the lack of financial resources for investment and maintenance and inefficient water management in most of water companies, water coverage and service quality are unsatisfactory. The water service quality has been deteriorating markedly for at least the last twenty years. More than 23 years after the Dayton Peace Agreement, access to water services has been unacceptably low or unreliable.

Non-revenue water levels in the Balkan countries are highest in Europe ranging from 41.5 (Serbia) to 75.72 percent (B-H), except for Croatia (where they reach 12.32%) (see Figure 1). High level of non-revenue water of 75.72 % for 2007 B-H indicates worn-out water pipe network and poor water supply management.

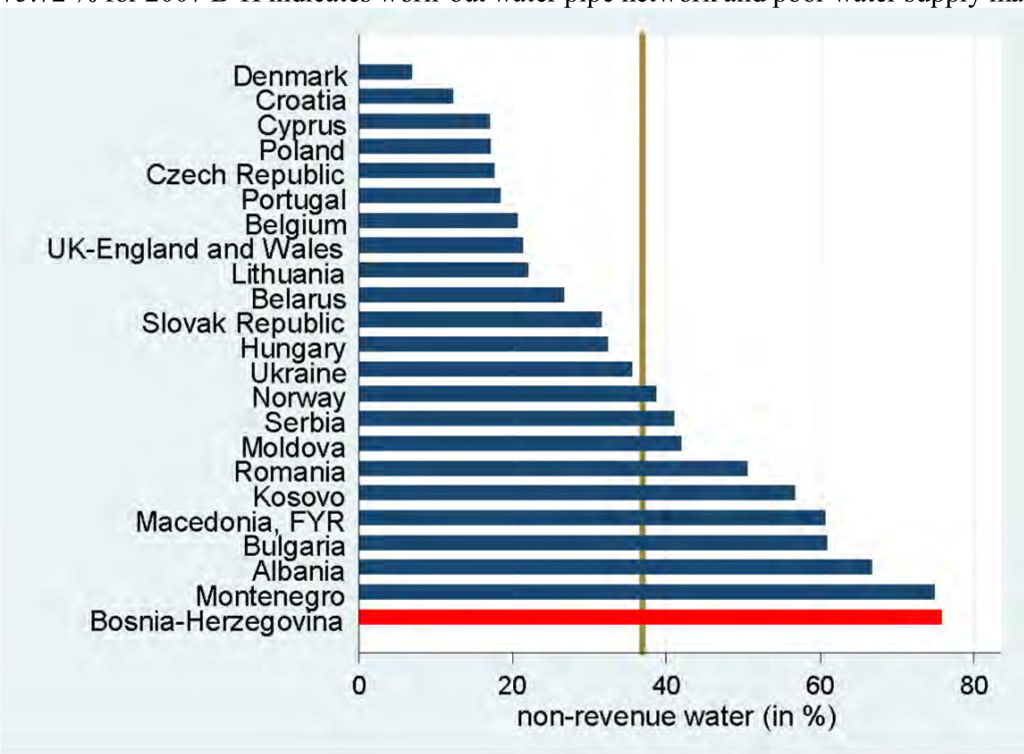

Figure 1: Non-revenue water; European countries, 2015

Bearing in mind the current ranking of B-H, it would be useful to assess properly the relative efficiency of water suppliers with the purpose of finding suppliers with the poorest performance i.e. those contributing most to such a position of B-H. This is of particular importance since the non-water revenues span from 0% (KP Park Mrkonjić Grad AD) up to 75.72% (KJKP ViK d.o.o. Sarajevo). (IBNET, 2018). Therefore some corrective measures such as introducing public-private partnership (PPP) could be introduced with the aim of efficiency improvements and input reductions.

3. Conceptual Framework and Methodology

Since its introduction by Aigner et al. (1977), stochastic frontier estimation has been extensively used to estimate technical efficiency in applied research (Kumbhakar et al, 2014). Among panel data models, which are the main focus in this paper, the inefficiency specification used by Battese and Coelli (1995) and Green (2005) are most frequently used in empirical studies (Kumbhakar et al, 2014).
In a standard panel data model, the focus is mostly on controlling firm effects (heterogeneity due to unobserved time-invariant factors). However, Kumbhakar et al. (2014) introduced a new model which fills several gaps in the standard panel data models by decomposing the time-invariant firm effect and a persistent technical inefficiency effec
The presence of such effects can be justified, for example, by making an argument that there are unobserved time-invariants inputs that are not inefficiency. The model is specified as (Colombi et al. 2014; Kumbhakar et al, 2014)

$$y_{it} = \alpha_0 \alpha_0 + f(x_{it}; б) + \mu_i + \nu_{it} - \eta_i - u_{it} \qquad (1)$$

where μ_i are random firm effects that capture unobserved time-invariant inputs.

The model has four components two of which (η_i and u_{it}) are inefficiency and the other two are firm effects and noise (μ_i and v_{it}). These components appeared in other models in various combinations but not all at the same time in one model. Estimation of the model can be done in a multi-step procedure, for which purpose the model in (1) is rewritten as

$$y_{it} = \alpha_0^* \alpha_0^* + f(x_{it}; б) + \alpha_i + \varepsilon_{it} \qquad (2)$$

where a $\alpha_0^* \alpha_0^* = \alpha_0 \alpha_0$ - $E(\eta_i) - E(u_{it})$; $\alpha\alpha_i = \mu_i - \eta_i + E(\eta_i)$; and $\varepsilon_{it} = \upsilon_{it} - u_{it} + E(u_{it})$. With this specification α_i and ε_{it} have zero mean and constant variance.

In a nutshell, it is possible to examine whether inefficiency is persistent over time or it is time-varying. The following questions related to the time-invariant individual effects is whether the individual effects represent (persistent) inefficiency, or whether the effects are independent of the inefficiency and capture (persistent) unobserved heterogeneity. Related to this is the question: whether the individual effects are fixed parameters or are realisations of a random variable. Comparing the efficiency of water operators, and recognising operator heterogeneity, it is possible to examine whether there is evidence of efficiency convergence, i.e. whether operators move toward the sector frontier or their relative inefficiencies remain unchanged. It is possible to find out the rate of efficiency change, whether the rate of frontier shift is significantly over time (Kumbhakar et al, 2015).

If the persistent inefficiency component is large for an operator, then it is expected to operate with a relatively high level of inefficiency over time, unless some changes in policy and/or management take place. Thus, the high value of u_i is of more concern form a long-term point of view because of its persistent nature. The advantage of the present specification is that it enables to test the presence of the persistent nature of technical inefficiency without imposing any parametric form of time-dependence. By including time in the x_{it} vector, it is possible to separate exogenous technical change from technical inefficiency. (Kumbhakar et al, 2015).

4. Results from the application of SFA to the B-H water industry

The data is collected from a survey of 130 water suppliers in B-H. The panel data in this case is unbalanced because the number of observations is not the same for each operator, and it spans from six to ten. In addition, the case is considered as a short panel since the number of operators (32) is greater than the number of time periods (10).
We estimated the production frontier for a sample of 32 water suppliers covering the 2000-2009 period.

Table 1 : A Sample Summary Statistics

Variables	Obs	Mean	Std.Dev.	Min	Max
Volume of delivered water (m^3/year)	296	1974548	5494382	4120	33690372
Volume of paid water (m^3/year)	296	934773	1736827	950	10647274
Delivered to households (m^3/year)	296	1512693	4410008	3290	27177083
Delivered to commercial consumers (m^3/year)	296	415179	1116436	640	6526282
Number of connections	296	6401	11637	162	66618
Number of connections with operating meter	296	5943	11703	14	66285
Household Connections	296	5648	10087	14	57778
Commercial Connections	296	718.9	1570	2	8839
Length of network (km)	296	148.1	189.9	7	1043
Length of main lines (km)	296	45.63	38.61	5	180
Number of employees	296	79.66	186.6	2	1075
Number of employees (in *hours*)	296	83.01	196.9	2	1130
Total salaries (in BAM)	296	1104055	2967563	21340	20488832
Total costs (in BAM)	296	3971942	12377229	73456	73910865
Total electricity costs (in BAM)	296	342639	1070050	2006	6840285
Total chemical costs (in BAM)	296	10167	29767	108	237925

Source: Domljan (2011)

By dropping one by one the statistically insignificant variables whilst ensuring that the model passed a number of other diagnostic tests for panel data it has got

$$\text{Ln(volume of paid water)} = \underset{(5.79)}{4.08} + \underset{(7.92)}{0.79}\ \text{ln(no. hous. connect.)} + \underset{(5.63)}{0.69}\ \text{ln(no. of employees)} \quad (3)$$

where *t*-ratios are given in parentheses.

The model suggests that, at least for this data set, the main production driver (volume of water paid) is the number of residential water connections followed by the number of employees.

As previously mentioned, the B-H water industry suffers from underinvestment. Accordingly, it is not surprising that inclusion of time (T) as a proxy for technological changes the variable T in the equation (3) is not of significant importance in explaining the production function.

Table 3 : Regression model

VARIABLES	(1) Model final
ln(no. household connection)	0.789***
	(0.0996)
ln(no. of employees)	0.694***
	(0.123)
Constant	4.082***
	(0.706)
Observations	296
Number of operators	32
R-squared	0.387

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

The logarithmic specification is consistent with a standard multiplicative production function and enables the direct estimation of elasticities. The model appears to be a "good fit" with R^2 = 0.387 (R^2 between = 0.895; R^2-overall = 0.887). All the variables are statistically significant and they have their expected signs. The sum of the coefficients on the two output variables reflects, at a value of 1.48, i.e. the presence of scale economies.

The interpretation of the coefficient of ln (number of household connections) of about 0.79 is that if the number of household water connections (proxy for capital) is increased by 1%, on average, the volume of paid water (m^3 per year) goes up by about 0.79%, holding the number of employees constant. Similarly, holding the number of employees constant, if the number of household water connections increased by 1%, on average, the volume of water paid (m^3 per year) goes up by about 0.69%. Relatively speaking, a percentage increase in the capital input contributes more towards the output than a percentage increase in the labour input (Gujarati, 2015).

Table 4 : Overall, persistent and residual efficiency of the B-H operators

Variables	Obs	Mean	Std. Dev.	Min	Max
TE_R_klh	296	0.8374192	0.0730689	0.5049769	0.9597189
TE-P_klh	296	0.6470689	0.1336849	0.2669283	0.8673154
OTE_klh	296	0.5423738	0.1226274	0.1892366	0.8003429

As illustrated in the Table 4, persistent efficiency is estimated to be 65 percent on average, residual efficiency 84%, and overall efficiency 54%. The average (across operators) of these efficiency measures is plotted over time in Figure 2 (Kumbhakar et at, 2015).

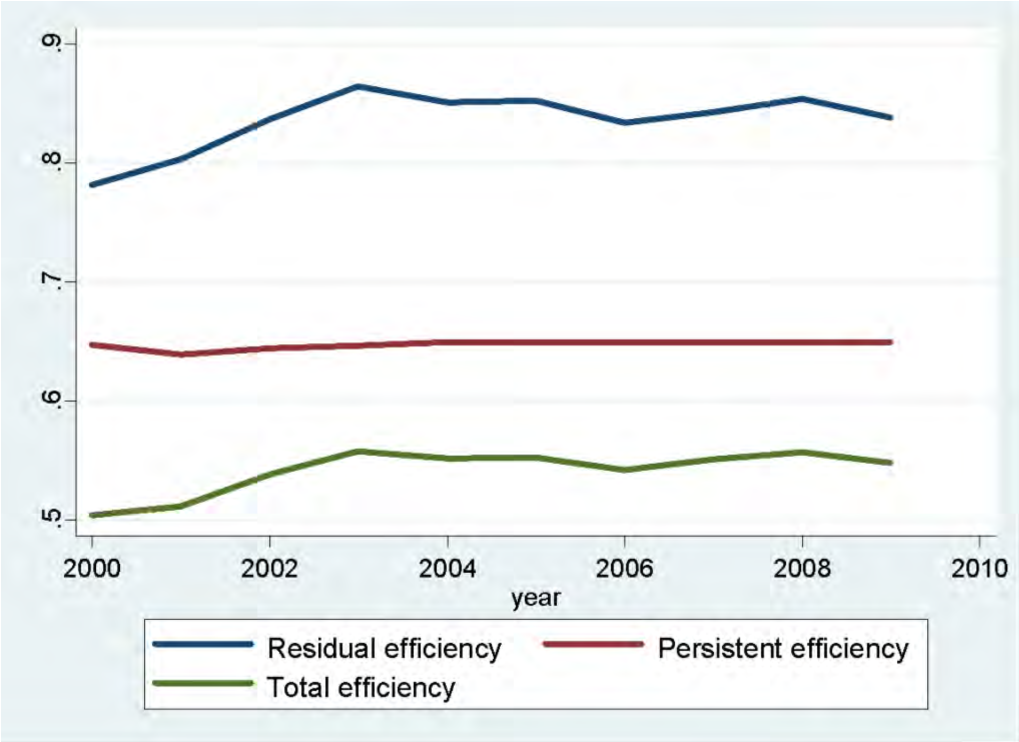

Figure 2: Efficiency of the B-H water operators

5. Proposal of introducing PPP

Bearing in mind that today's market is radically different from those of the1990s (when dominated by the large concession model and a strong interest of private investors to finance projects) or the 2000s (contract terminations and nervousness about the benefits that PPP could bring in the water supply sector) (Rigby Delmon, 2015), two models of PPP in water supply sector seem feasible in B-H (see Table 5).

Table 5: Potential models of private sector involvement in the B-H water sector

	Management contract	Lease/affermage contract
Definition and responsibility of the operator	a private contractor takes responsibility for management services to the utility in return for a fee	a private contractor operate and maintain utility, employ staff, retains revenues from customer tariffs, pays lease fee to the contracting authority
Profit function for operator	Fixed fee+ bonus-managers' salaries and related expenses	Revenue from customers – operating and maintenance costs – lease fee
Asset ownership and capital investment	Public	Public
Commercial risk	Public/private	Public/Private
Repair and renewal of existing system	No	Yes
Operations/maintenance	Private	Private
Contract duration	3-5 years	5-10 years

Source: Adapted from Budds and McGranahan (2003) and Rigby Delmon (2015)

Under a management contract, the municipal authority makes a private contractor responsible for running the distribution system but retains responsible for investment and expansion and employing the workforce. It transfers certain operation and maintenance responsibilities to a private company for three and five years. Remuneration for managing the water service is either fixed in the form of a flat rate or rather performance-related.

Affermage/lease contracts are similar to management contracts, but with a rather important difference: the private sector operator takes responsibility for all operation and maintenance, including billing and revenue collecting. Under this type of contract, a private company is responsible for delivery of water service, and for necessary investments in reparing and renewing the existing assets, while the public authority remains responsible for new investments and for the investments in extensions. Affermage/lease contracts involve private investment in renewing the network, but not in extending the system making fiscal space less of a limitation (Domljan and Domljan, 2010).

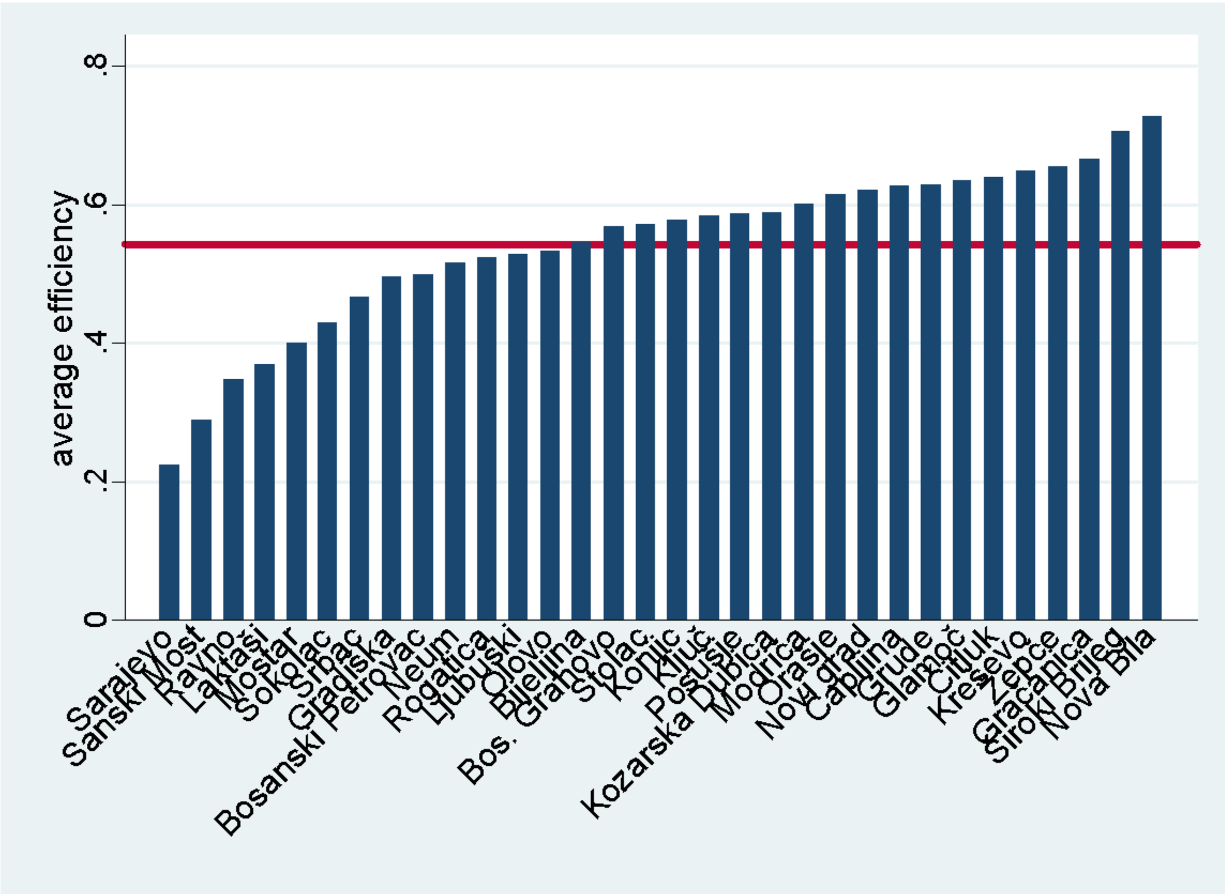

Figure 3: Efficiency of water operators; B-H, 2000-2009

The first candidate for introducing the PPP in B-H should be the least efficient and at the same time the largest operator, KJKP ViK d.o.o. Sarajevo (see Figure 3).

5. Conclusions

The research demonstrated that the B-H policy makers should focus on reforming the water system commencing with the most inefficient operators in order to minimize enormous water losses. A large number of the operators do not seem to be operating at the minimum level of resource input. It is necessary to make radical changes in the water sector in having it closer to the EU acquis communitaire (see the Water Framework Directive).

The B-H small and fragmented i.e. municipally owned and regulated water sector suffers from weak financial strength and lack of qualified and trained staff. A high level of investment in the water system should be undertaken in the years to come to improve the network and to meet more demanding water quality standards. However, municipalities find it difficult to deal with the financial and technical issues posed by water. It seems that the acceptable approach for the B-H would be to employ the two-step approach: first, a short-mid term management contract then a longer-term lease contract with a private operator.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Hololens – A New Teaching Tool in Construction Education

Pavan Meadati, PhD
Department of Construction Management, Kennesaw State University, Marietta, Georgia, USA
pmeadati@kennesaw.edu

Amin Akhnoukh, PhD, PE
Department of Construction Management, East Carolina University, Greenville, North Carolina, USA
Akhnoukha17@ecu.edu

Abstract

Students have different learning styles and the use of technological gadgets became an integral part of their life. Engaging these technology savvy students in the learning process with their preferred learning style is a challenging task. The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude. This active student engagement challenge can be addressed by using hologram-learning environment provided by Microsoft Hololens. This learning environment engages students in active learning processes and helps them to focus on their learning. It also encourages students to take more responsibility for their own learning process. This learning environment provides a new teaching style and helps the instructor to address some of the needs of the students' learning styles. This paper discusses about the hologram-learning environment. This paper also discusses about the progress of the pilot study conducted to engage the technology savvy visual learners in a concrete formwork course.

Keywords

Hologram, Hololens, learning styles, concrete formwork, construction management

1. Introduction

Technology became an integral part of Construction Management (CM) students' life. CM students using the technologies for school related work will continue to grow in future. Students have different learning styles. Traditional lecture is one of the styles, which is widely used for teaching CM courses. Additionally, two-dimensional (2D) drawings are most widely used as pedagogical tools for teaching CM courses to the students. The interpretation of 2D drawings by students varies based on their educational background, previous practical experience, and visualization capabilities among other factors. Students are required to develop three-dimensional (3D) models mentally by visualizing the different components of the project. Students with little or no practical experience often face challenges and spend more time in developing 3D visual models. Sometimes construction site visits are included to complement the lecture format style. This teaching style provides visual and verbal learning environment. However, inclusion of site visits within the course schedule is not always feasible due to reasons such as unavailability of construction sites meeting the class needs, class schedule conflicts, and safety issues (Haque, 2007). Due to the lack of adequate visual learning environment, currently CM students are unable to gain the required skills to solve real world problems (Irizarry et al, 2012). The differences in teaching and learning styles result in problems such as disengagement of students and loss of learning aptitude (Wasim et al. 2011). Engaging these technology savvy students with their preferred learning style in the learning process is a challenging task. Hologram-learning environment helps to address this active student engagement challenge. Microsoft Hololens helps to accomplish this type of learning environment. This learning environment engages students in active learning processes and helps them to focus on their learning. It also encourages students to take more responsibility for their own learning process. This learning environment provides a new teaching style and helps the instructor to address some of the needs of the students' learning styles. The following sections discuss about the hologram-learning environment followed by the details of the pilot study that is in progress to engage the technology savvy CM students.

2. Hologram-Learning Environment

“Holography is a technique that enables a light field, which is generally the product of a light source scattered off objects, to be recorded and later reconstructed when the original light field is no longer present, due to the absence of the original objects.” (Wikipedia 2018). Holography is one of the emerging technologies and one of its potential applications include holographic telepresence (Walsh, 2012). This facilitates users to interact live in person in 3D. This enables the students to have remote collaboration, conduct experiments, have virtual site visits, interact with the gaming environment, design and print project in three dimensions and helps instructors to teach multiple classrooms across globe simultaneously (Team ISTE, 2015 & Walsh, 2012). Hololens is the first self-contained holographic computer developed by Microsoft, which facilitates to view and interact with 3D images. The following section discusses about Microsoft Hololens.

2.1 Hololens

Microsoft Hololens is the self-contained, holographic computer. This enables to engage with the digital content and interact with holograms in the world around the user (Microsoft 2018 a). It is made up of specialized components such as HoloLens Processing unit (HPU) and advanced sesnsors. These components together enable holographic computing. It’s advanced sensors capture information about what user is doing and the environment in which the user is in. It can see, map, and understand the physical places, spaces, and things around the user. It understands gestures and where user looks, and maps the world around the user, all in real time. It has a “see-through holographic high-definition lenses” and an advanced optical projection system. This generates a multi-dimensional full-color images with very low latency so that user can see holograms in their own world. It’s headband is designed to distribute the wieght around the crown of the user head and saves ears and nose from undue pressure. Headband has an adjustment wheel which ensures comftable fit for a wide range fo adult head sizes. Though it has more computing power than the average laptop, it is passively cooled without fans.Lack of wires, external cameras, or phone or PC ocnnection required makes the user to move freely (Microsoft 2018 b).

Figure 1: Microsoft Hololens (Microsoft 2018 a)

3.0 Pilot Study

A pilot study to demonstrate the feasibility of hologram-learning environment to address the challenge of actively engaging technology savvy CM students is in progress at Construction Management Department of Kennesaw State University. The study includes three steps: (a) Students learning styles assessment (b) Formwork repository development, and (c) Usability study. Below sections present the overview of these step.

3.1 Students learning styles assesment

The objective of this step is to assess the learning styles of the students enrolled for the concrete formwork course. The assessment helps to assess the applicabiltiy of the.hologram-learning enviroment to address the 3D visualization challenge faced by CM students. Index of learning styles questionnaire proposed by Soloman and Felder of North Carolina State university (Felder and Solomon, 2017) was used to assess the learning styles. It is an on-line instrument questionnaire and has 44 questions. Once the survey is submitted the learning styles of the student are presented on scale score ranging from 1 to 11 in increments of 2 for each learning style. Depending on the score, the students preference to particular learning can be classified as “fairly well balanced” (score on scale 1-3), “moderate” (score on scale 5-7), and “very strong” (score on scale 9-11) (Felder and Solomon, 2017). Fairly well balanced indicate that the student is flexible in adopting either learning style. Moderate indicates student’s moderate preference to particular learning style. Very strong indicates student’s strong preference to particular style (Felder and Solomon, 2017). A screen shot of the submitted survey results is shown in Figure 2. For this study, visual and verbal category was only considered. Each student of the course was asked to complete the survey. The results of the survey were then analyzed to assess the different learning styles of the students in the course. Total 16 students were enrolled in the course. The survey results indicated that all students are visual learners. As shown in Figure 3, based on the scores 6%, 44% and 50% were considered as fairly well balanced, moderate and very strong visual learners respectively. The following sections discuss how HoloLens was used for engaging students and their experiences on the usability of the hologram-learning environment.

Figure 2: Screen shot of the learning styles survey results

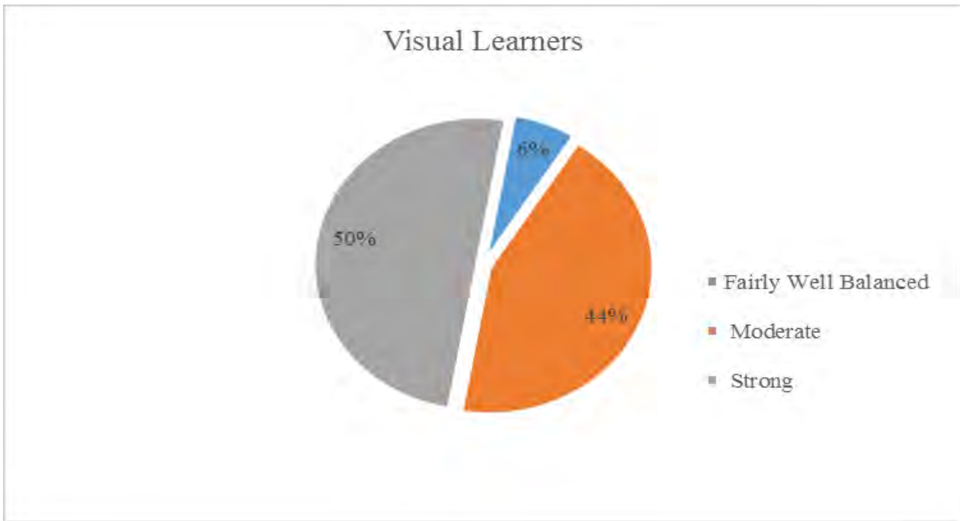

Figure 3: Visual Learners and their preferences

3.2 Formwork repository development

In this step, a repository of 3D models and holograms of the concrete formwork were develoepd. The 3D models were developed using Revit 2017. These were developed using existing families and creating new families. The developed 3D models include column formwork (see Figure 4), slab formwork (see Figure 5), wall formwork (see Figure 6) and a multistory building formwork (see Figure 7). These 3D models were converted into appropriate hololens readable hologram file format.

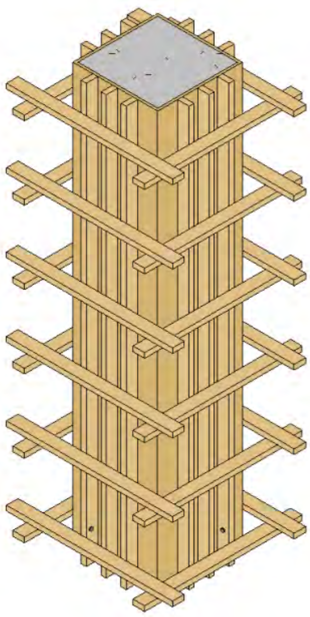

Figure 4: 3D model of a column formwork

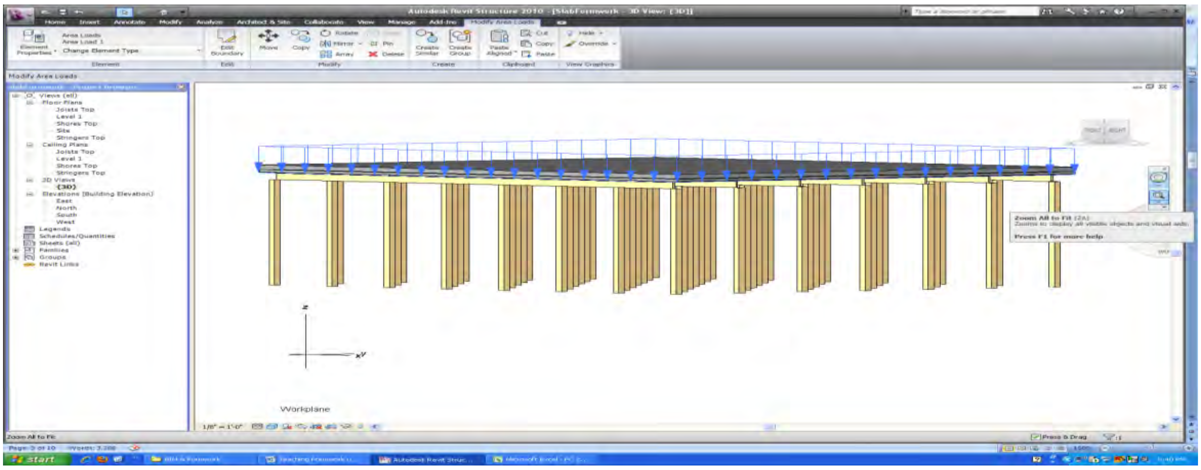

Figure 5: 3D model of an elevated slab formwork with vertical load

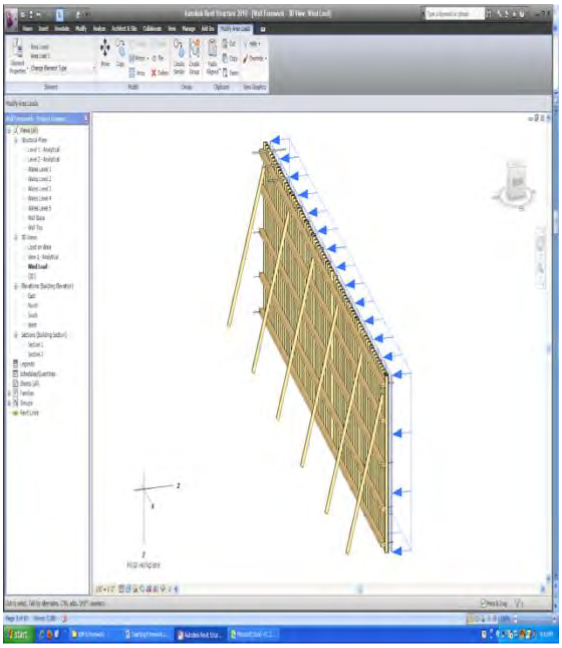

Figure 6: 3D model of a wall formwork with wind pressure

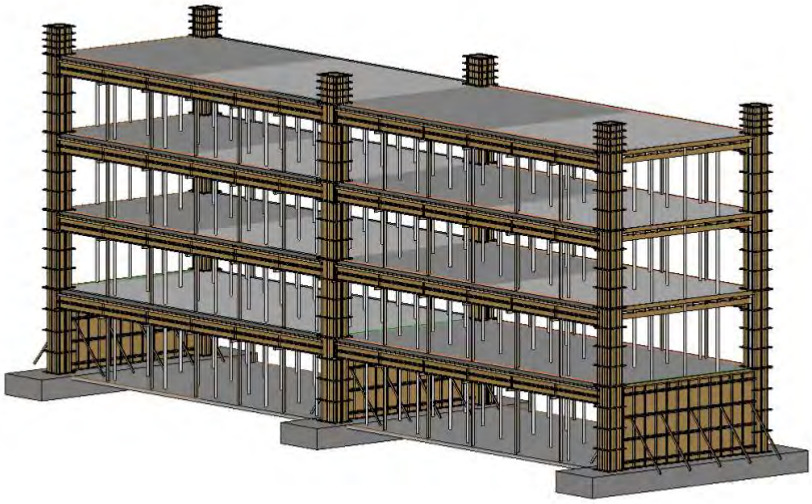

Figure 7: 3D model of a multistory formwork

3.3 Usability study

A usability study is in progress. In this study, the CM students use Hololens to view and interact with holograms in the hologram-learning environment (see Figure 8). After interaction with the holograms, the students are asked to express their satisfaction on usefulness, ease of use and ease of learning of hologram-learning environment with 5-point Likert-type scale (1= Strongly Agree, 2 = Agree, 3=neutral, 4= Disagree, and 5=Strongly Disagree). The data collection in this step is in progress. Table 1 includes the survey questions included under usefulness, ease to use and ease of learning to use categories.

Table 1: Survey questions included in the Usability Study

Usefulness Category
1. It helps me be more effective.
□ It helps me to be more productive.
□ It is useful.
□ It saves me time when I use it.
f Use Category
1. It is easy to use.
□ It is simple to use.
□ It is user friendly.
□ It requires the fewest steps possible to accomplish what I want to do with it.
□ Using it is effortless.
f Learning to Use Category

1. I learned to use it quickly.

- I easily remember how to use it.
- It is easy to learn to use it
- I quickly became skillful with it.

4. Conclusion

Hologram-learning environment serves as a new teaching tool and helps the instructors to be more effective in communicating the information to the students. This learning environment provide 3D visualization and helps students to be actively engaged in the learning process. The hologram-learning environment has the potential to make a paradigm shift in teaching and learning process. The pilot study discussed in this paper serves as an initial step to extend the hologram-learning environment to various CM courses.

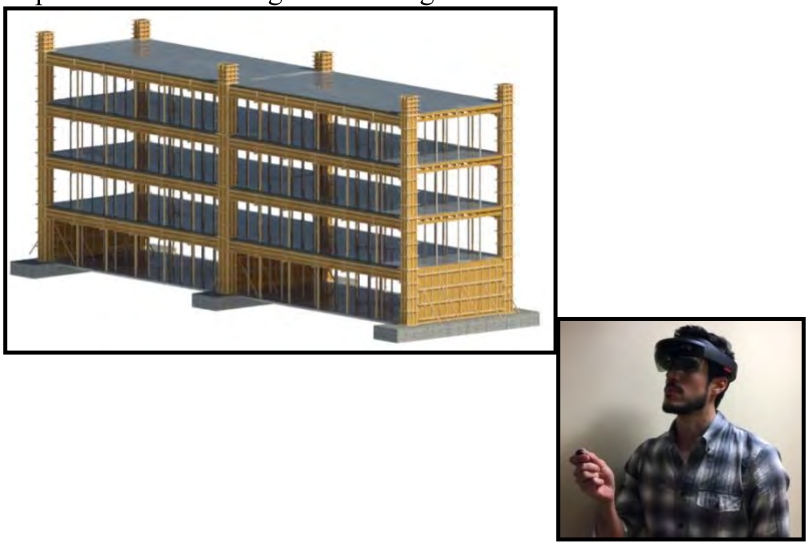

Figure 8: Student interacting with hologram using hololens

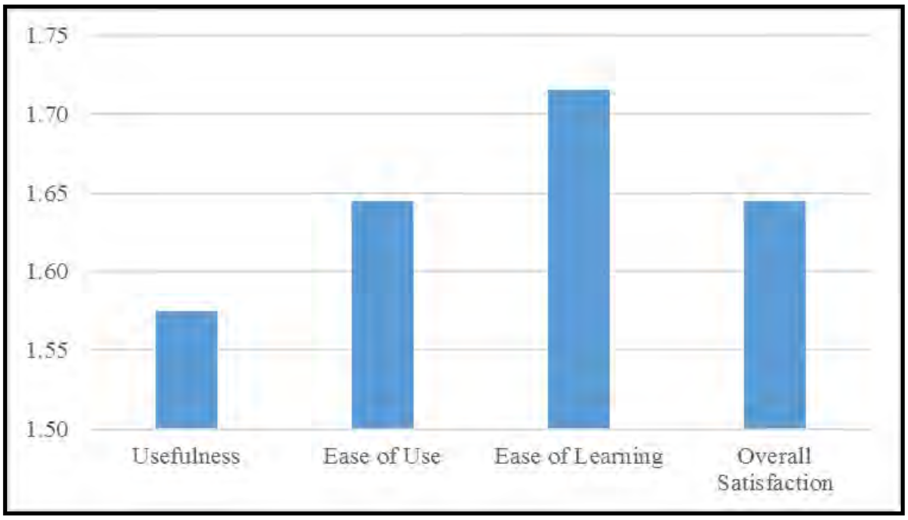

Figure 9: Hologram-learning environment usability results

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

State of Practice on Project Delivery Decision-Support Models for Water and Wastewater Capital Projects

Jeffrey Feghaly, A.M.ASCE
Graduate Student and Research Assistant, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ, U.S.A.
jfeghaly@asu.edu

Mounir El Asmar, Ph.D., A.M.ASCE
Co-Director of the National Center of Excellence on SMART Innovationals, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ, U.S.A.
asmar@asu.edu

Samuel T. Ariaratnam, Ph.D., P.E., P.Eng., F.ASCE
Professor and Construction Engineering Program Chair, Ira A. Fulton Schools of Engineering, Arizona State University, Tempe, AZ, U.S.A.
ariaratnam@asu.edu

Abstract

The construction industry is rapidly evolving and pushing for innovative ways of project delivery. Despite traditional Design-Bid-Build (DBB) project delivery still prevailing, owners are now opting for alternative project delivery methods (APDM) such as through Design-Build (DB) and Construction Management at Risk (CMAR). APDM have been gaining popularity across numerous sectors, notably in the transportation sector; however it is not yet as widely adopted in the water infrastructure sector. Several agencies and organizations within the transportation and education sector have generated decision-support models to aid owners in selecting the best project delivery method (PDM) for their projects, based on maneuvering within a certain framework containing key PDM selection factors. Five decision-support models currently utilized in the airports, transit, transportation and education sectors will be evaluated in this paper. This overview will detect all key project delivery selection factors within each framework and reveal commonalities across all of them, aiming to combine the strengths of all models under one optimized decision-support tool to be later used for the water infrastructure sector.

Keywords

Alternative Project Delivery Method, Project Delivery Selection Factor, Decision-Support Models

1. Introduction

There is a growing need to renovate and upgrade existing aging water and wastewater treatment plants across the United States. According to the American Society of Civil Engineers (ASCE), the existing U.S. water and wastewater infrastructure systems received low grades of "D" and "D+", respectively on the 2017 ASCE Infrastructure Report Card (ASCE 2017). With a significant drop in federal funding from \$16 Billion USD in 1976 to \$4.4 billion USD in 2014, the problem of deteriorating infrastructure has fallen under the responsibility of individual States and municipalities (CBO 2015). Therefore, it is vital for water infrastructure sector leaders to choose project delivery methods that will maximize their financial investments, ensure efficient engineering design, and complete projects on time and within budget.

A project delivery method (PDM) can be termed as the process that will be utilized by the owner over agreements with other stakeholders and entities to commence with the planning, financing, design, construction, start-up and operation of a construction project. PDMs are known to be recognized by two fundamental characteristics: (1) contractual relationships between project stakeholders and (2) their timing of engagement in the project (Konchar and Salvido 1998; Molenaar et al. 1999; El Asmar et al. 2013).

Different PDMs have their own particular advantages and disadvantages depending on several unique project related factors. Despite traditional Design-Bid-Build (DBB) prevailing as the most applied PDM, owners are now opting for alternative project delivery methods (APDM) such as through Design-Build (DB) and Construction Manager at Risk (CMAR). In DBB, the contractor is typically not involved in the design phase and will only be included once 100% design has been completed. However, with APDMs such as CMAR, the construction team is involved with the design phase early on, and in DB the contractor is involved during around 20% of design completion (El Asmar et. al. 2013).

This overview will detect key project delivery selection factors of five PDM frameworks and reveal commonalities across the different models, aiming to combine all models under one optimized decision-support tool to be subsequently used in the water infrastructure sector.

2. State of Practice

It is essential for water and wastewater decision-makers to possess a tool to allow them to screen and evaluate their project delivery options. The Airport Cooperative Research Program (ACRP), Transit Cooperative Research Program (TCRP), Colorado Department of Transportation (CDOT), Washington State Department of Transportation (WSDOT) and the Alaska Department of Education and Early Development (ADEED) PDM decision-support models are reviewed and serve as a preliminary study for the implementation of a water infrastructure specific project delivery selection tool. A nonexhaustive sample of these models are presented in Table 1.

Table 1: Existing Project Delivery Section Decision-Support Models

Organization	Year	Application Sector	Title
ACRP	2009	Airports	A Guidebook for Selecting Airport Capital Project Delivery Methods
TCRP	2009	Transit	A Guidebook for the Evaluation of Project Delivery Methods
CDOT	2014	Transportation	Project Delivery Selection Matrix
WSDOT	2016	Transportation	Project Delivery Method Selection Guidance
ADEED	2017	Education	Project Delivery Method Handbook

In the following section, the project delivery selection decision-making models presented in Table 1 are briefly summarized and the major selection factors of each project delivery method identified.

2.1 ACRP – "A Guidebook for Selecting Airport Capital Project Delivery Methods"

The ACRP (2009) provides a two-tier system for project delivery selection, allowing airport capital projects owners and decision-makers to evaluate the advantages and disadvantages of certain PDMs such as the DBB, CMAR, and DB methods. Tier 1 is known as the *Analytical Delivery Decision Approach* and offers a straightforward six-step approach shown in Figure 1, allowing decision-makers to comprehend the elements and characteristics of each project delivery method.

Figure 1: ACRP Tier 1 Six-Step Approach (2009)

It is important during Step 5 of the Tier 1 process to review the advantages/disadvantages of each PDM individually against certain selection factors. 19 selection factors or project level issues are identified in Figure 2 and are categorized by the four major pertinent issues (based on surveys and research conducted by the ACRP) that influence PDM selection:

Project-Level Issues
1. *Project size/complexity* 2. *Schedule compression* 3. *Schedule growth control* 4. *Early cost precision*
5. *Cost control* 6. *Risk management/allocation* 7. *Lifecycle costs* 8. *Maintainability*
Airport-Level Issues
9. *Airport experience/staff capability* 10. *Airport control of project* 11. *Security* 12. *Control of impact on passengers and operations* 13. *Third-party stakeholder input to design and construction*
Public Policy/Regulatory Issues
14. *Competition and local talent* 15. *DBE/small business impacts* 16. *Legal and statutory constraints* 17. *Sustainability and LEED certification*
Other Issues
18. *Adversarial relationships* 19. *Construction claims*

Figure 2: ACRP Selection Factors or Project Level Issues for Airport Projects (2009)

Tier 2 utilizes a weighted-matrix delivery decision approach for PDM selection, established on the basis of prioritizing project objectives and calculates a score corresponding to each PDM. The Tier 2 *Weight-Matrix Delivery Decision Approach* consists of five distinct steps presented in Figure 3.

Figure 3: ACRP Tier 2 Five-Step Approach (2009)

The main intent of Step 1 of the Tier 2 approach is to reduce the 19 PDM selection factors of the Tier 1 approach to a maximum of 7 prominent factors to remain in use. Step 2 consists of ranking these remianing factors and obtaining their factored weight, allocating points to each factor based on importance. Step 3 provides a project delivery scoring scale that is to be multiplied with the factored weight from Step 2 to obtain the weighted score of each PDM. The PDM with the highest total score will be chosen as the most appropriate for a project. The two-tier system forces decision-makers to document the entire PDM selection process, serving as a reference for owners to make decisions for future projects.

2.2 TCRP – "A Guidebook for the Evaluation of Project Delivery Methods"

As an extension on the ACRP's (2009) two-tier approach, the TCRP's (2009) framework provides a third tier consisting of a risk analysis section for project delivery selection, allowing transit project owners to evaluate the pros and cons of different PDMs, comprising of the DBB, CMAR, DB and design-build-operate-maintain (DBOM) methods. The 24 PDM selection factors in this guidebook are identified in Figure 4.

Project-Level Issues
1. *Project size* 2. *Cost* 3. *Schedule* 4. *Risk management* 5. *Risk allocation* 6. *LEED certification*
Agency-Level Issues
7. *Agency experience* 8. *Staffing required* 9. *Staff capability* 10. *Agency goals and objectives*
11. *Agency control of project* 12. *Third-party agreements*
Public Policy/Regulatory Issues
13. *Competition* 14. *DBE/small business impacts* 15. *Labor unions* 16. *Federal/State/Local laws*
17. *FTA/EPA regulations* 18. *Stakeholder/Community input*
Lifecycle Issues
19. *Lifecycle costs* 20. *Maintainability* 21. *Sustainable design goals* 22. *Sustainable construction goals*
Other Issues
23. *Construction claims* 24. *Adversarial relationships*

Figure 4: TCRP Selection Factors or Project Level Issues for Transit Projects (2009)

Unlike the ACRP's framework, if a PDM is not selected by the end of Tier 2, decision-makers will then move to a two-phased Tier 3 optimal-risk based approach. The first phase involves a qualitative analysis and requires owners to develop a risk-allocation matrix containing a maximum of two PDMs. The second phase of Tier 3 is a quantitative approach and analyzes each PDM against project schedule and cost and allows owners to chose the most advantageous PDM.

2.3 CDOT – "Project Delivery Selection Matrix"

Simillary to the TCRP's (2009) framework, the Colorado Department of Transportation's (CDOT) "Project Delivery Selection Matrix" also suggests an extensive three-staged process which offers a structured approach for facilitating transit decision-makers in selecting the appropriate PDM. The PDMs in this matrix are the DBB, DB, and the Construction Manager / General Contractor (CM/GC) or what is also known as CMAR. Stage 1 consists of documenting project attributes, goals, and constraints. Stage 2 involves assessing 5 primary PDM selection factors. Finally, Stage 3 comprises of evaluating 3 secondary PDM selection factors. The three-staged decision-making process of CDOT's decision-support model is illustrated in Figure 5**.**

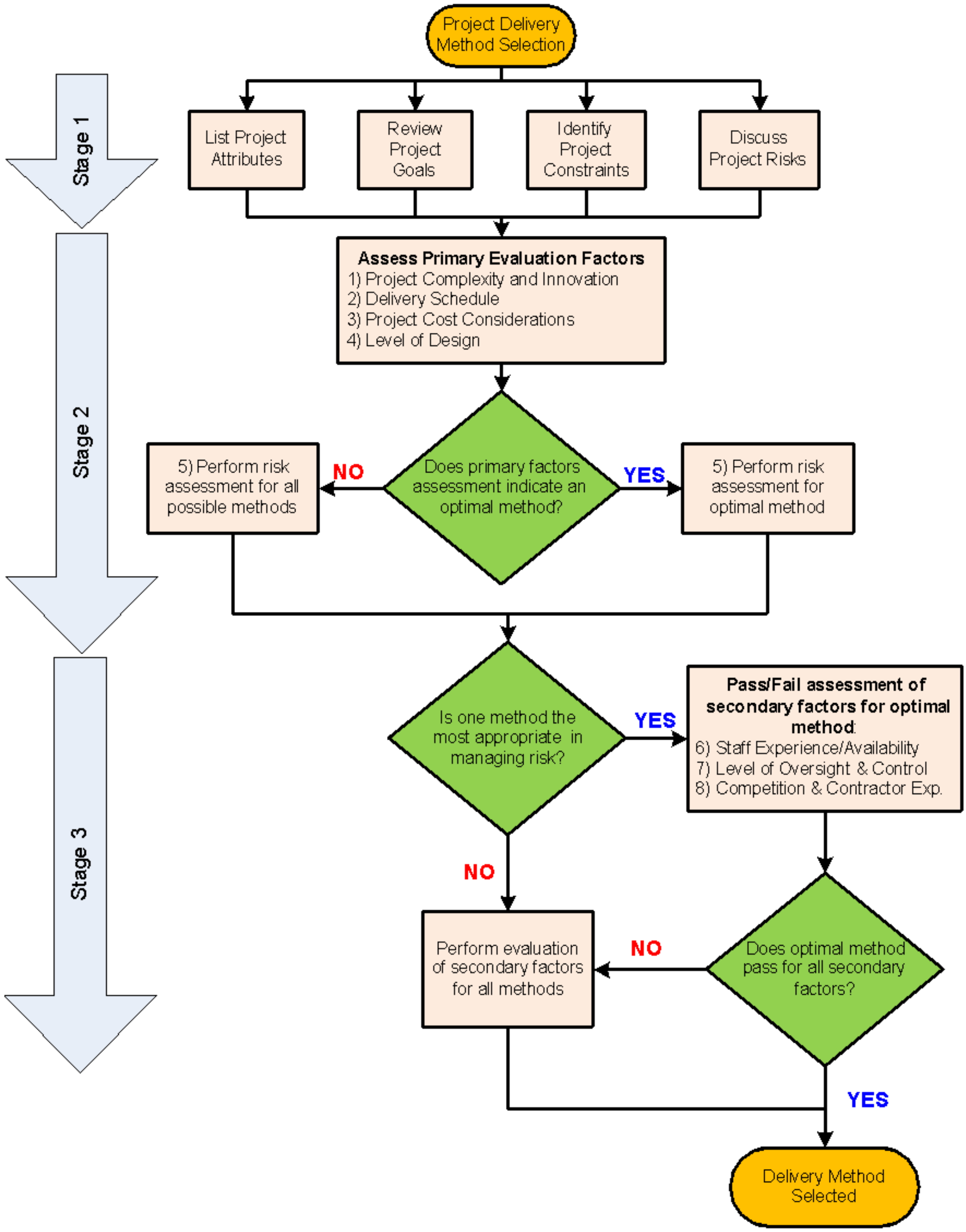

Figure 5: CDOT PDM Selection 3-Stage Approach (2014)

2.4 WSDOT – "Project Delivery Method Selection Guidance"

The Washington State Department of Transportation (WSDOT) adopted the CDOT's PDM selection approach and developed their own two-stage personalized PDM guide. Stage 1 is the probable PDM determination process and its first step is to document project attributes, goals, and constraints. It successively checks if a project has a project cost of $25 Million USD or more, if the cost is above that threshold it will direct the decision-makers to complete a selection matrix which compares PDMs with 10 selection factors presented in Figure 6.

Selection Factors
1. *Project delivery schedule* 2. *Funding limitations* 3. *Project cost* 4. *Third-party agreements*
5. *Owner's involvement and control* 6. *Lifecycle costs* 7. *Minimizing facility operations disturbance*
8. *Encourage room for innovation* 9. *Minimizing owner risk* 10. *Minimizing impact on local businesses*

Figure 6: WSDOT PDM Selection Factors (2016)

However, if project cost is under $25 Million USD it will direct owners to a selection checklist. This process will eventually lead decision-makers to the determination of a probable PDM. After the completion of Stage 1, Stage 2 consists of selecting a final PDM by undertaking an extensive validation and revision process of the probable PDM obtained in the earlier stage.

2.5 ADEED – "Project Delivery Method Handbook"

With the same amount of selection factors as the WSDOT's decision-support model, the ADEED handbook establishes a framework to aid owners in the education sector in selecting the appropriate PDM. ADEED identifies 6 need factors and 4 success factors, and assesses these factors against each PDM. The 10 key factors and need factors are identified in Figure 7.

Need Selection Factors
1. *Project delivery schedule* 2. *Amount of overlapping design/construction* 3. *Scope definition*
4. *Potential for change during construction* 5. *Need/Desire for contractors' input in design*
6. *Flexibility to make changes after construction completion*
Success Selection Factors
7. *Owner's ability to manage design* 8. *Owner's ability to eliminate disputes between parties*
9. *Regulatory and statutory requirements* 10. *State budget and funding cycles*

Figure 7: ADEED Need and Success PDM Selection Factors (2017)

3. Synthesis of the Models and the Factros

Inherently, each PDM decision-support framework was developed to cater to the needs, concerns, and objectives of individual sectors. However, after compiling the selection factors across the five models as demonstrated in Table 2, it can be observed that all models shared common PDM selection factors. These major selection factors are essential across various PDM selection frameworks and are to be used to design an optimized decision-support tool to be potentially utilized within the water infrastructure sector.

Table 2: PDM Selection Factors Across the Decision-Support Models

PDM Selection Factors	ACRP (2009)	TCRP (2009)	CDOT (2014)	WSDOT (2016)	ADEED (2017)	TOTAL
Project Delivery Schedule	X	X	X	X	X	5
Owner Involvement & Control	X	X	X	X	X	5
Risk Management & Allocation	X	X	X	X		4
Project Cost Control	X		X	X		3
Lifecycle Costs	X	X		X		3
Third-Party Involvement	X	X		X		3
Competition	X	X	X			3
Disadvantaged Business Enterprise	X	X		X		3
Legislation & Regulation	X	X			X	3
Adversarial Relationships	X	X			X	3
Staffing Requirements & Capabilities	X	X	X			3
Project Size	X	X				2
Early Cost Estimates & Precision	X	X				2
Maintainability	X	X				2
Owner Experience	X	X				2
Impact on Existing Facility Operations	X			X		2
Sustainability Goals	X	X				2
Community/Stakeholder Input		X	X			2
Project Complexity & Innovation			X	X		2
Funding				X	X	2
Construction Claims	X	X				2
Safety	X					1
Owner Goals & Objectives		X				1
Labor Unions		X				1
Level of Design			X			1
Contractor Experience			X			1
Amount of Overlapping Design & Construction					X	1
Scope Definition					X	1

Potential for Change During/After Construction					X	**1**
Need for Contractor's Input in Design					X	**1**

Committing to a *project delivery schedule* is typically the most significant challenge within construction projects; hence it is not unexpected to see this PDM selection factor present within all explored frameworks. Moreover, *owner involvement and control* is identified in all five decision-support models as it is crucial for the owner to define their capabilities and role within the construction project team, this in turn can dictate the best suited form of project delivery.

Other selection factors are addressed to accommodate for a concern of a specific sector a certain framework is serving. For example, the *impact on existing facility operations* selection factor is mentioned within the ACRP framework, as new airport construction projects should take into consideration existing airport operations and traffic. Another sector-specific concern example would be *funding* within the ADEED decision-support model, as educational institutions are generally financed and dependent on federal or local budget cycles and funding.

Additionally, ADEED’s framework is the most recent decision-support model between the five frameworks; implying that its developers have had more experience and insight into the recent alternative project delivery market. Hence, its unique additional selection factors such as *contractor’s input in design, scope definition, amount of overlapping design and construction, and potential for change during and after construction completion,* are arguably emerging selection factors in the field of PDM selection.

The five models have collectively produced 30 PDM selection factors, which are all respectively worth delving into further and considering when producing an optimized decision-support tool aimed at the water infrastructure sector.

4. Conclusion and Next Steps

This paper explored existing PDM decision-support models currently being used within the airports, transit, transportation and education sectors in the United States with the aim of compiling data for the creation of an optimized PDM selection framework to serve the water infrastructure sector. The key selection factors across the five decision-support models were identified and then ranked in order of appearance and repetition; leading to a collection of 30 distinctive project delivery selection factors. These 30 selection factors will be further explored and potentially utilized when creating a decision-support tool to serve the water infrastructure sector in the future. A limitation of this paper is the lack of quantity and variety of sector-driven PDM decision-support models in this study, as there are several potentially significant PDM selection factors and frameworks currently overlooked. Future research will aim to accumulate further comprehensive data by exploring additional models and increase significance on compiled PDM selection factors.

5. Acknowledgements

This work is funded by the Water Research Foundation (WRF) Project #4685 “Project Delivery Performance Evaluation and Decision Support Tool for Water and Wastewater Capital Projects.”

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A review of client loyalty to construction professional service firms.

Nick Williams
School of Architecture and Built Environment, University of Wolverhampton, UK
N.Williams@wlv.ac.uk

Dr Paul Hampton
School of Architecture and Built Environment, University of Wolverhampton, UK
P.Hampton@wlv.ac.uk

Dr Nii A Ankrah
School of Architecture and Built Environment, University of Wolverhampton, UK
Nii.Ankrah2@wlv.ac.uk

Dr Ezekiel Chinyio
School of Architecture and Built Environment, University of Wolverhampton, UK
E.Chinyio@wlv.ac.uk

Abstract
The global demand for construction professional services is rising but many construction professionals have neither the time nor the skills to effectively market their services offerings. Therefore, retaining and developing existing client accounts is vital. Firms with a loyal client base have lower marketing expenditure, are better able to retain talented employees and have more predictable revenues. The problem addressed by this review paper is understanding the extent of current knowledge regarding client loyalty for construction professional service firms operating in the business-to-business sector. An in-depth literature review revealed that although there is a body of research relating to customer-loyalty in wider business-to-business services, few studies were found in respect to construction professionals. The review also indicated a considerable variation in how loyalty and construction professional services have been operationalised. Furthermore, little is known regarding the extent to which client loyalty is targeted towards construction professional services firms, their employees or both. A conceptual model of client loyalty to construction professional service firms is proposed, based on the findings of the literature review. Future empirical research, accounting for the findings of this paper would be of value to both academics and construction professionals.

Keywords:
Construction professional services; Loyalty; Commitment; Professional service firm.

1. Introduction.

A review of client loyalty to construction professional service (CPS) firms is provided in this paper. CPS firms make a substantial contribution to the construction industry and wider economy. In the financial year 2005/2006 they generated £13.9 billion worth of revenue in the UK (CIC, 2008). The market for specialist architectural and quantity surveying services in the UK alone was worth £4.1 billion in 2011 (DBIS, 2013). Despite these facts, few CPS firms have either the skills or the inclination to effectively market their services (Sawczuk, 2010). In respect to professionals, Amonini *et al* (2010 p.30) go as far as describing “a distain for commercialism” due to a fear of perceived salesmanship. Furthermore, many professions operate within a framework of professional and ethical obligations which constrain more ruthless aspects of selling and opportunism (Simon, 2005). Professionals are often required to adhere to technical codes, having only a limited ability to differentiate their service offerings (Sweeney, Soutar, and McColl-Kennedy, 2011). Therefore, the importance of repeat-business to CPS firms cannot be overstated. Developing stronger and longer-lasting relationships leads to lower risks and transaction costs, to the benefit of both service providers and their clients (Sheth and Parvatiyar 1995). Client loyalty is even more important for firms operating in the business-to-business (B2B) sector as they generally have fewer client accounts, each contributing a larger proportion of firm revenues. Despite this, the amount of research dedicated to professional-client relationships is modest (Broschak, 2015) with even less having been carried out in respect to construction professionals.

The problem addressed by this review paper is understanding the extent of current knowledge regarding client loyalty for construction professional service firms operating in the business-to-business sector. Also addressed is the additional problem of understanding where client loyalty may be targeted in respect of CPS firms, their employees or both. An objective is to review how construction professional services have been studied and if they are a homogenous group for research purposes. The paper is structured into 5 sections. The next section provides a methodology. After that CPS firms and client loyalty are discussed, followed by antecedents, a conceptual model of CPS client loyalty and conclusions.

2. Methodology.

An in-depth literature review was carried out examining the subject area of CPS firms and loyalty in wider B2B service markets. Searches were carried out on both Google Scholar and the University of Wolverhampton’s library and its databases. Analysis was restricted to published journal articles which were read in full. The keywords used were ‘construction professional’ and ‘construction professional services’ sorted to 50 key articles. These were triangulated with ‘loyalty’ but yielded too few results, requiring the wider professional service firm and business-to-business (B2B) service loyalty literature to be reviewed. The analysis of loyalty was undertaken using 19 articles which operationalised loyalty in a business-to-business service context, prioritising the findings of those which focused on professional service industries. A conceptual model of client loyalty for PCS firms is proposed based on the findings of the literature review.

3. Construction Professional Service (CPS) firms.

Professional service firms (PSF’s) are understood to have particular characteristics which demand distinctive management theories. Von Nordenflyct (2010) identified three defining characteristics of PSF’s, specifically: (1) knowledge intensity; (2) a professionalised workforce; and (3) low capital investment. Professional characteristics vary between different professions, depending on the type of service delivered and the market in which they operate. Trait heterogenity has restricted wider research on the professions mainly to law and accountancy practices which researchers are confident fit the model of a PSF (Von Nordenflyct, Malhotra and Morris, 2015). Furthermore, there has been a tendency for scholars to make broad generalisations across the wider PSF sector on the back of such research which may not hold true for CPS.

Figure 1 shows the subject matter of the CPS articles reviewed. Client loyalty and relationship management generally in respect of CPS appears to be underexplored. Other than a related article on client-switching behaviour in property services (Levy and Lee, 2009) no articles could be found in regard to CPS and client loyalty.

Figure 1. Subject matter within the CPS research reviewed.

Another aspect considered is whether sub-disciplines within CPS are sufficiently homogenous to research collectively. The definition of CPS in this study was adapted from CIC (2008 p.3) who define this group as including "architects, quantity surveyors, surveyors (other), building services engineers, civil and structural engineers, planners (town planners), project managers and multidisciplinary practices". Chan, Chan and Scott, (2007) argue that different construction professions have similar traits, such as self-regulation sanctioned by government authorities, a requirement to adhere to a codes of conduct and membership of a professional institution. Chan, Leung and Yuan (2014) argue that construction professionals of different sub-disciplines face similar job adversities, such as task-complexity, tight deadlines and often-adverse working relationships. Furthermore, CPS in general are often dynamic, time-consuming and require working with multiple diverse disciples. Previous CPS research was reviewed to support the assumption that they are similar enough to be studied as a whole. The findings in Table 1 show that 62% of of the articles reviewed gathered data from more than one CPS sub-profession but studied them collectively. Only 24% of articles reported findings separately by sub-profession. Table 2 summarises how the findings of this group of articles were reported. Half of the articles identified differences between the sub-professions, particularly between design and non-design CPS professionals in respect to goal orientation, personality characteristics, leadership style and team roles adopted. For example, Akiner and Tijhuis (2007 p.113) found that architects valued "freedom" and "challenge" job aspects more so than civil engineers. It was noted that research aims rarely included the identification of differences between sub-professions, most focussing on collective CPS findings.

Table 1. CPS Research design by sub-profession.

Research design – collective or separate CPS sub-profession data	Proportion of articles
CPS studied collectively with no distinction between sub-professions	31 (62%)
Results reported separately by sub-profession	12 (24%)
Studies of one sub-profession only	7 (14%)

Table 2. Findings of CPS articles gathering separate data for sub-professions.

Findings of articles analysing data by sub-profession	Proportion	Example Articles
Articles analysing data for sub-professions separately which identified differences between them	50% (6 articles)	Akiner & Tijhuis (2007), Graham, (2010)

Articles analysing data for sub-professions separately which focused on the results for CPS collectively	50% (6 articles)	Bowen et al (2007), Bowen, Edwards and Lingard (2013)

4. Client Loyalty.

Sawczuk, (2010) cites the myriad of benefits gained by CPS firms in sustaining client-relationships which include: increased revenues; reduced marketing spends; reduced risk due to experience of serving the client; the ability to ring-fence resources to a loyal client, leading to efficiencies; and better staff retention due to a sense of security. Jewell, Flanagan and Lu (2014) found via a survey of CPS provider firms, that an average of 70% of revenues were achieved from only 30% of their client base.

Loyalty is a more complex concept than mere retention and re-purchase. Some scholars have criticised studies that only consider *behavioural loyalty,* claiming that they are insufficiently explanatory and fail to distinguish between spurious and true loyalty (Rauyruen and Miller, 2007). Furthermore, mere patronage of a service provider may be due to habit or contractual lock-in (Russo *et al* 2016). A*ttitudinal loyalty* in a B2B context has been defined as “the level of customer's psychological attachments and attitudinal advocacy towards the service provider/supplier” (Rauyruen and Miller, 2007. p.23). Clients who have high behavioural loyalty, but low attitudinal loyalty are more susceptible to attrition and may be more responsive to offers by competitors. Watson *et al,* (2015 p.803) propose an overall definition of loyalty, accounting for both attitudinal and behavioural elements, defining it as “a collection of attitudes aligned with a series of purchase behaviours that systematically favour one entity over competing entities”.

A review of the B2B service loyalty literature revealed a marked inconsistency in how loyalty has been defined and operationalized as shown in Figure 2. Studies have used attitudinal measures (Jayawardhena *et al, 2007*), behavioural measures (Williams *et al*, 2011) or both (Huang, Leu and Farn 2008). Watson *et al*, (2015) recommend that loyalty studies should include both attitudinal and behavioural measures as there is a greater association with desirable outcomes for the firm when used together, compared to when they are used in isolation. Furthermore, they recommend that for researchers seeking to identify how loyalty is built that behavioural and attitudinal loyalty should be measured and reported separately as antecedents differently effect each element.

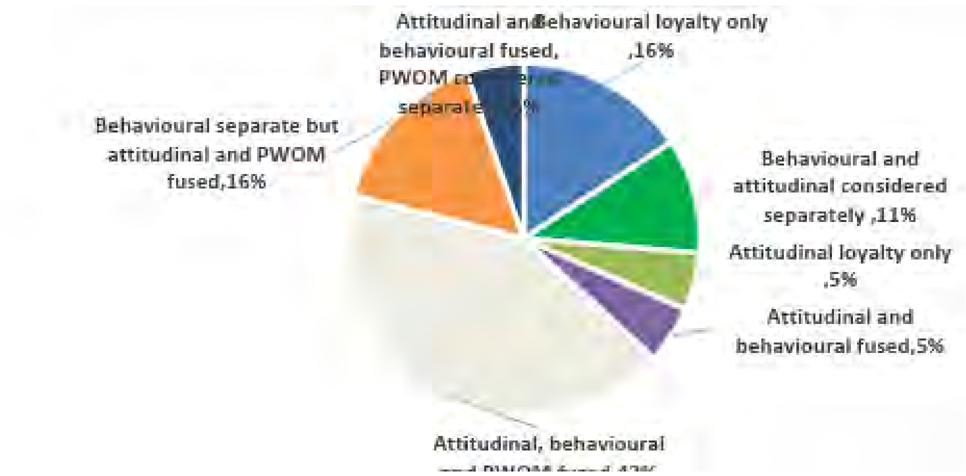

Figure 2. Different ways in which loyalty has been operationalised.

There are also variations in the literature regarding the temporal orientation of loyalty measures. Some scholars have developed them to be ‘prospective’ (forward-looking), some are retrospective (backward looking). By way of example, Cahill *et al,* (2010 p.269) operationalises loyalty via referrals retrospectively as “*have* recommended”. However, Wu, Chen and Chen (2015 p.339) use “…would definitely recommend” a similar measure but in a prospective (forward-looking) tense. A mix of forward-looking and backward-looking measurement items were found in over half of the B2B service loyalty literature studies reviewed.

Watson *et al* (2015) found this inconsistency to be problematic both in terms of inferences one can make and the like-for-like comparison with other studies.

Longitudinal studies in wider B2B services have suggested that loyalty is dynamic, the influence of different antecedents varying over the duration of the client-service provider relationship (Curran, Varki and Rosen, 2010). For practicability reasons, most loyalty studies reviewed using surveys were cross-sectional. In most cases, the limitations of such an approach was aknowledged in the respective articles, as should be case for any future research adoping a similar design.

Another aspect of client loyalty is its target, given that it can be directed at the firm, the key-contact employee or both. The impact of employee loss from professional firms has attracted recent academic attention. Broschak and Block (2014) found that the loss of client accounts is associated with employee mobility. If client loyalty is directed towards the individual employee rather than the firm, there is a risk that the individual may leave the business, the benefits of loyalty being lost with them. Notwithstanding employment contracts with restrictive covenants, the damage could be even worse if the employee is lost to a competitor leading to the client switching. Many loyalty articles conflate these loyalty dimensions, failing to tease out where customer loyalty is directed. Only 16% of the B2B service loyalty articles reviewed considered key-contact employee loyalty and firm loyalty separately. In their mixed-industry study, Anaza and Rutherford (2014) found that client loyalty to employees was positively associated with loyalty to the firm. However, research regarding the target of loyalty, its risk and benefits in respect to CPS is lacking.

5. Antecedents of Loyalty.

Scholars are divided on the relative importance of *rational factors* or *affective factors* influencing loyalty (Williams *et al,* 2011). Catar and Catar (2009) demonstrated a positive association with *social bonds* and client commitment in professional relationships. *Communication effectiveness* between professional service providers and clients has been associated with perceived service quality, trust and commitment (Sharma and Patterson, 1999). *Trust* has long been understood to be a critical component of service relationships (Parasuraman, Zeithaml and Berry, 1985). This issue of trust is closely tied with professional ethics. As Koene (1994, in Dinovitzer *et al,* 20015 p.118) asks "if professionals are not trustworthy, whom should we trust?" A commonly cited definition of trust in a commercial setting is "a willingness to rely on an exchange partner in whom one has confidence" (Moorman Deshpande and Zaltman, 1993 p.82). Trust takes on even greater performance for B2B services as buyers are faced with determining the value of service provider offerings in the face of technical complexity and intangibility. Morgan and Hunt (1994) found that trust and commitment are important mediating variables, this relationship also being demonstrated within professional services settings (Catar and Catar, 2009; Catar and Zabkar 2009). Creating and communicating *value* is important for all professional service providers. Christopher (1996. p.58) states that "customer value is created when the perceptions of benefits received from the transaction exceed the costs of ownership". Value is what you *get* compared to what *give* and has been shown to have a direct positive influence on loyalty in professional service settings (Trasores, Weinstein and Abratt; 2009; Sarapaivanich and Patterson, 2015). *Satisfaction* in a B2B service context has been defined as "a positive affective state, resulting from the appraisal of a firm's working relationship with another firm" (Geyskens, Steenkamp, and Kumar, 1999.p.95). Customer satisfaction has been positively associated with both purchase intention and attitudinal loyalty in B2B service markets (Rauyruen and Miller, 2007). Despite this, Narayandas (2005) argues that the satisfaction is poorly correlated with loyalty in B2B markets. Clients may prefer a service provider who provides an overall lower level of satisfaction to another if they can be trusted to deliver more consistently. *Commitment* in a B2B service context is an implicit or explicit pledge of relationship continuity between the exchange partners (Dwyer Schurr and Oh, 1987). Commitment has been defined as "an enduring desire to maintain a relationship" (Moorman, Zaltman and Deschpande, 1992 p.316) and has been conceptualized as having both affective (relational) and calculative (rational) dimensions. Affective commitment is similar to attitudinal loyalty and has been conceptualized as an antecedent to loyalty operationalised by positive word-of-mouth (Catar and Catar, 2009; Catar and Zabkar, 2009) and repurchase intentions (Morgan and Hunt, 1994). Clients use *reputation* to make determinations of professional service quality (Broschak, 2015). It has been defined as "a collective assessment of a company's attractiveness to a particular group of stakeholders, relative to a reference group of companies with which the company competes for resources" As Mahotra (2003. p. 953) states in respect to individual professionals within a consultant engineering firm "they certainly leverage on their association with a brand-name but cannot match the greater history of experience of the firm".

6. Outcomes of loyalty.

Recommendations and referrals, are the lifeblood of many CPS firms, particularly smaller ones with less marketing resources. Most of the B2B service loyalty articles reviewed (92%) used positive word-of-mouth (PWOM) measures within their loyalty constructs. Recent theoretical and empirical arguments have been presented that PWOM is a separate phenomenon and should not be used as a measure of loyalty. PWOM is socially complex and is influenced by self-image, consideration for others and serendipitous encounters. A consumer setting example of the drawbacks of using PWOM to indicate loyalty is that a customer may be loyal to a condom brand but unlikely to recommend it. Although perhaps not having such a stark effect in a B2B service setting, a professional client may be more or less likely to recommend a service, depending on its importance and interest within a firm or peer-group.

7. Conceptual Model.

The conceptual model in Figure 3 proposes a mechanism for client loyalty to CPS firms integrating the findings of several key studies regarding commitment and loyalty antecedents in professional service relationships (Catar and Catar, 2009, Harvey and Wayne Mitchell, 2015; Sharma and Patterson, 1999, Sarapaivanich and Patterson, 2015; Trasorras and Abbrat, 2009). The model also integrates the relationship between key-contact employee and firm loyalty (Anaza and Rutherford (2014). The association between between loyalty and firm performance in terms of turnover, share of client spend and profitability is included (Watson *et al*, 2015).

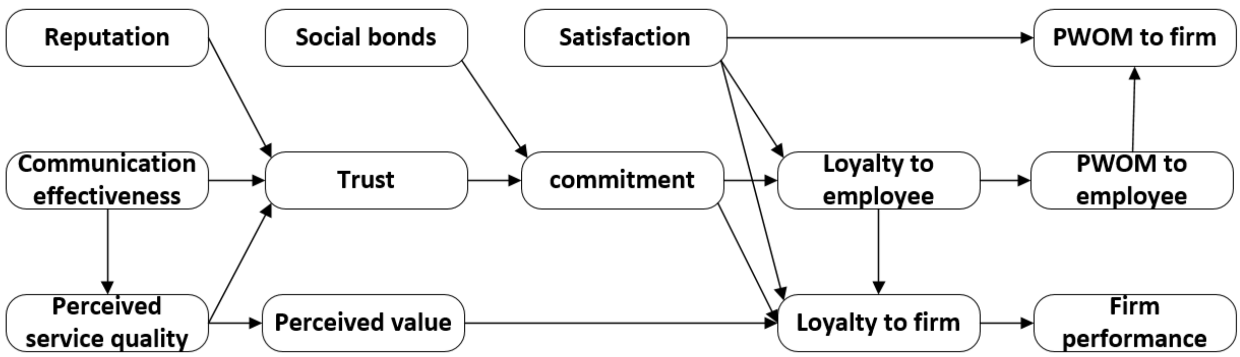

Figure 3: Model of client loyalty to CPS firms and their key contact employees – A conceptualisation of the researchers.

8. Conclusions.

Either by virtue of research design or empirical findings, most of the extant research reviewed treated CPS as an homogenous group. Most prior studies made no distinction beteween the different sub-professions when gathering data or when discussing the findings. Future research should account for variation in CPS client loyalty antecedents, in particular between design and non-design professions.

The review revealed important findings which should be accounted for during the design of future CPS client loyalty research. Variations were found in how loyalty has been operationalised in terms of a behaviour, an attitude, or both. A better understanding of the antecedents and outcomes of loyalty would be achieved by considering and measuring the attitudinal and behaviour aspects of loyalty seperately. The temporal orientation of survey measures should be carefully designed and internally consistent to augment predictive power and allow like-for-like comparisons with other loyalty studies. Furthermore, the dynamic nature of loyalty over the duration of relationships should either be accounted for in the research design or the study limitations. While PWOM is important for CPS firms in terms of generating new business, it is conceptually different from loyalty and should be measured separately as an outcome rather than an indicator. Research is lacking in respect of the target of CPS client loyalty. Firms risk losing the benefits of loyalty if it is centred towards employees who defect to other firms. Furthermore, evidence is lacking in regard to whether loyalty to employees translates into loyalty to their employers and therefore if it is to be encouraged or discouraged by CPS firms.

In conclusion, client loyalty to CPS firms was found to be a neglected subject. Future research, empirically testing the findings of this review would add to current knowledge as well as being of practical interest to construction professionals.

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Key Performance Indicators: Advances in Construction Projects Performance Measurement

Hatzigeorgiou Alexandros
Postgraduate Course in Engineering Project Management, School of Science and Technology, Hellenic Open University, Patra, Greece
alexhatz1973@gmail.com

Manoliadis Odysseas
Department of Civil Engineering, Democritus University of Thrace, Xanthi, Greece
omanoliadis@yahoo.com

Abstract

The last two decades, performance measurement in the construction industry has shifted towards a more holistic and integrated assessment of the overall construction project success, with the implementation of appropriate Key Performance Indicators providing essential information for project monitoring and construction management processes control. This paper attempts a critical literature review of recent trends on performance measurement systems developed for construction projects, focusing on the development and application of related Key Performance Indicators, by presenting some of the most significant published studies in construction and project management journals. The two main objectives of this review is first to examine whether the issue of sustainability is addressed in the presented studies, and in what extend, and second to inspect if these studies are considering performance evaluation throughout the construction project Life Cycle. After a short report on the most applied modern performance measurement frameworks in construction and the creation and evolution of Key Performance Indicators, a succinct presentation of the reviewed studies is following, summarizing and reporting their basic features in an extensive table. Finally, concluding remarks and comments are given.

Keywords

Key Performance Indicators, Performance Measurement, Life Cycle Assessment, Sustainability Criteria

1. Introduction

Performance Measurement (PM) has gained significant attention during the 1990s among academics, researchers and professionals in most of the economy's sectors. The new trend quickly expanded in the construction industry, with more and more construction engineering organizations adopting Performance Measurement Systems (PMSs) (Bassioni et al., 2004). A rough distinction in the application of PMSs in construction is at a macro level, that is the industry, and at a micro level, that is the construction project. Although PM in construction initially used to focus on project performance, strictly following the classical "Iron Triangle" approach in terms of time/cost/quality, the evolution over the last decades has led PM objectives to extend to construction firms and to the project stakeholder level. Meanwhile, performance at the construction project level incorporated the evaluation and assessment of the overall project success in a more holistic and integrated manner, viewing the construction project as a product.

Project performance evaluation throughout the entire life of a project has been a concern for academics and researchers since the last two decades. Jugdev and Muller (2005) concluded that views on project success have changed over the years from limited definitions restricted to the implementation phase of the project, to definitions reflecting appreciation of success over the entire project and product Life Cycle (LC). Yet, in the case of construction projects, most of the PMSs, theoretically or empirically developed, do not seem to take into consideration the entire LC of the project, the process of which includes conception and feasibility studies, engineering and design, procurement, construction and operation or utilization. Related literature and various definitions (Kibert, 1994; Ritz, 1994, Shen et al., 2007) suggest five major phases to compose a construction project's LC, namely: *i) Inception:* an initial pre-project phase where the project idea is born and its primary objectives are defined, including also opportunity and feasibility studies leading to investment decisions, *ii) Design:* involves the preparation of detailed construction drawings and analytical designs of structural, electrical or other systems, supplemented by contract documents and written conditions containing legal requirements and commitments, *iii) Execution:* the phase of the actual construction of the project, including the pre-construction stage where various subcontractors are recruited and the project site is organized and the actual construction stage, where the various physical activities are undertaken, *iv) Operation:* the time period upon which the completed project will function as a product and will be used by the project's stakeholders (clients, end users, neighbors etc.) and *v) Demolition:* the final stage of the project's LC, indicating the termination of the project's life by the decomposition of its basic structures and facilities.

Sustainability performance across a construction project's LC is a critical aspect in achieving the primary goal of sustainable development, while the impacts of construction activities on it can be considered in three main dimensions: *social, economic,* and *environmental*. Various management approaches have been developed (Kibert, 1994; Hill and Bowen, 1997) and lists of sustainability performance factors were formulated (Shen et al., 2007) to assist and improve sustainability performance in construction projects. However, specific sustainability measures and indices are not often included in the PM process implemented in construction projects.

Taking into consideration these two recent trends of LC analysis and sustainability in construction projects' PM, the aim of the paper is to present a thorough literature review and a critical reporting of published studies, during the last two decades, on PMSs developed strictly for construction projects. The two main objectives are on the one hand, to examine whether the issue of sustainability in construction projects is addressed in the developed PMSs, and in what extend, and on the other, to inspect if the presented PMSs for construction projects are considering performance evaluation and project LC analysis. For the selection of the presented studies, major and highly-ranked project or construction management journals were considered.

2. Performance Measurement in Construction

2.1. Contemporary Performance Measurement Frameworks Applied in Construction

The gradual abundance of traditional PMSs during the past thirty years, led to the development of numerous models and frameworks for implementing PM, aiming to bridge the gap between financial and non-financial measures and considering several other critical aspects, like quality management, customer and employee's satisfaction, processes optimization etc. Yet, not all of them experienced wide implementation in construction. The *European Foundation for Quality Management (EFQM) Excellence Model,* the *Balanced Scorecard (BSC)* and *Key Performance Indicators (KPIs)* are considered to be the most frequently used by a number of researchers (Bassioni et al., 2004; Yang et al., 2010).

The *EFQM Excellence Model*, a non-prescriptive framework developed in 1989 in Europe, has emerged as a major tool in the development of continuous business improvement, aiming to improve performance and to enable the assessment of excellence. (EFQM, 1999). The model consists of five enabler's criteria, dealing with how the various activities are undertaken and representing the management of the organization, and four sets of results criteria, focusing on what results an organization have achieved. Despite its original mission as a business quality and excellence model, the EFQM Excellence Model has been used ever since as a PM framework (Bassioni et al., 2004) and has been adopted by many construction companies. *BSC*, introduced in the early 1990s by Kaplan and Norton as a new comprehensive PMS, comprised a framework that can translate a company's vision and strategy into a coherent and linked series of measures and sub–measures, allowing an organization to measure and evaluate its performance through four distinct perspectives: Financial, Customer, Internal Process and Learning & Growth Perspective. Although BSC intended to serve as the basis of a typical PMS, it was further promoted as a strategic management system, organized on a cause-and-effect relationship base between the four perspectives (Kaplan and Norton, 1992;1996). Yang et al. (2010) considered BSC as the most frequently used PM framework in construction industry. *KPIs* constitute performance metrics of processes critical to the company's success and indispensable for benchmarking and project monitoring. Such models, developed generically, have been widely applied in the construction industry, establishing a system for the continuous performance improvement, in order to eliminate inefficiency and maximize cost effectiveness and productivity **(**Cha and Kim, 2011).

2.2. Key Performance Indicators in construction industry and projects

During the 1990s two landmark reports, published by Sir Michael Latham (1994) *"Constructing The Team"* and by Sir John Egan (1998) *"Rethinking Construction"* respectively, set out specific targets for performance level improvement in the construction industry, in terms of project performance, productivity, profitability, client satisfaction and quality & safety. In response to these two reports, the Construction Best Practice Program (CBPP), a government funded organization, was established in the U.K., launching the first KPI Programme in 1998. CBPP developed a first set of 10 headline KPIs in November 2000, serving as a measure of the overall state of a company's health, roughly classified into three categories: *economic, respect for people* and *environment*. On project performance, KPIs provide information regarding *construction cost, construction time, predictability cost, predictability time, defects, client satisfaction for product* and *client satisfaction for service*, while company performance is addressed from the perspectives of *safety, profitability* and *productivity* (CBPP, 2002). These headline KPIs were further classified as: i) operational indicators, used to measure specific activities and ii) diagnostic indicators, providing information on why certain changes may have occur in the headline or operational KPIs (KPI Working Group, 2000).

CBPP was soon acknowledged as the leading organization in the production of KPIs for the construction industry and its merging with the *"Rethinking Construction"* movement created in 2004 the Constructing Excellence (CE) Programme of the U.K (CE, 2006). CE compares pilot projects of the "Rethinking Construction" movement, from the KPI viewpoint, verifying the need for the introduction of a PMS in the construction industry, for the improvement of its competitiveness and management's efficiency. In the case of the U.S, the importance of performance assessment in increasing competitiveness and growth was acknowledged in the early 1990s. The Benchmarking & Metrics Programme (B&MP) of the Construction Industry Institute (CII) is another widely known construction initiative for PM, aiming to provide the construction industry with a common set of metric definitions and performance norms (Costa et al., 2006). B&MP reported a first collection of performance data in 1996 and its current review includes a set of indicators classified in the categories of *budgeted & actual cost, planned & actual schedule, facility capacity, outcomes, accident data* and *impact factors*. Its goal is to set performance standards in the construction industry using a consistent PM algorithm and to develop assessment tools in order to promote construction performance (CII, 2001).

Although KPIs, especially those of CBPP, proved very successful in introducing the topic of PM to the construction industry, they have been criticized as merely lagging indicators with limited use for internal management decision making, since they do not give insight for post event performance improvement (Bassioni et al., 2004). According to Beatham et al. (2004), KPIs are rarely incorporated into a proper PMS since they do not offer a real opportunity for organizational or performance change and they are more suited for cross-industry benchmarking purposes.

3. Presentation of related studies

Chan et al. (2002) modified the generic success criteria to develop an assessment framework for Design and Build (D&B) projects. Adopting the view that project success criteria change with time, they analyzed project success from the three conceptual phases of a construction project: the pre-construction, the construction and the post-construction phase. In their study, a list of success criteria for design/build projects, appearing in previous studies, was incorporated and categorized as objective and subjective measures. Their objective measures were described as hard and tangible and included *Time* and *Cost*, measured in the pre-construction and the construction phases, *Health & Safety*, considered in the construction phase, and *Profitability*, measured in the post-construction phase. On the contrary, subjective measures were termed as soft, intangible and less measurable, including *Quality* and *Technical performance*, assessed and measured in the pre-construction and the construction phase, *Functionality*, considered in the post-construction phase, *Productivity*, considered in the construction phase, *Project participants' satisfaction*, assessed in all three phases, and finally *Environmental sustainability*, measured in the post-construction phase. For each one of the objective and subjective criteria measures, common and widely applied KPIs were proposed.

Cox et al. (2003) acknowledged the necessity of identifying common indicators, for construction executives and managers, in measuring projects' performance and investigated management perceptions of quantitative and qualitative KPIs utilized in construction. They generated an initial set of perceived KPIs, through literature research, and conducted a survey in order to administer them to construction projects. Performing statistical analysis of the collected responses, in order to determine common KPIs by construction sector and by management or experience level, they concluded that the reported KPIs generally differ according to management's perspectives. Nevertheless, they identified six top rated indicators, including: *Quality control, On-time completion, Cost, Safety, Cost/Unit* and *Units/Man-hours*, reported as the most significant and useful by every construction sector.

Following the Chan et al. (2002) study, Chan and Chan (2004) developed a conceptual framework for evaluating success and measuring performance of construction projects. A set of KPIs, measured both objectively and subjectively, was collected through a comprehensive literature review and based on earlier research and their validity was tested with three case studies. Nine KPI categories in total were selected and divided into two groups, representing the objective and subjective criteria respectively, according to the calculation methods of the proposed KPIs. The first group, implementing mathematical formulas to calculate the respective values, included the categories of *Time, Cost, Value & Profit, Health & Safety* and *Environmental performance*. The second group, incorporating subjective opinions and personal judgement of the stakeholders, included *Quality, Functionality, User expectation & satisfaction* and *Participants' satisfaction* of various stakeholders. Similar KPIs with the ones reported to the Chan et al. (2002) study, were proposed for the nine success criteria.

Yeung et al. (2007), arguing that KPIs can serve as a benchmark for PM in construction partnering projects, developed a comprehensive performance evaluation model of partnering projects in Hong Kong. Utilizing a previously developed KPIs' conceptual framework, they applied the Delphi technique conducting a four-round questionnaire survey with a large number of construction experts, in order to rank and address weighs to the initial indicators list. Their results revealed seven top-weighted KPIs, including: *Time/Cost/Quality performance, Top management commitment, Trust & Respect, Effective communications* and *Innovation & Improvement.* In addition, a composite partnering Performance Index

(PI) was derived to provide an integrated assessment of partnering projects' performance. In a consequent study, Yeung et al. (2009), following an identical procedure and applying the same Delphi technique, formulated a model to assess the success of relationship-based construction projects in Australia. Eight KPIs were selected this time, excluding *Top management commitment* and adding *Safety performance* and *Client's satisfaction* in the previous list of KPIs, and a PI has been also derived. In both studies, the developed indices were composed of a set of lagging KPIs and could be used to measure, monitor, and improve the performance of construction partnering and relationship-based projects.

Li (2010) build an indicator-oriented PMS based on BSC, aiming to evaluate international engineering projects in a more comprehensive and accurate way. Considering the two aspects, results and processes, of the overall performance evaluation process of an engineering project, he made necessary amendments and modifications to the classical BSC in order to adjust it as an engineering-project-oriented PMS, including non-financial and qualitative indicators. Stating that international engineering projects differ substantially from domestic ones, and as a result performance indicators should be modified accordingly, he established a set of 1st class and 2nd class KPIs under the SMART principle, based on related literature. The 12 selected 1st class KPIs for the four BSC perspectives of his model were: i) Finance: *Profit potentiality, Finance operating conditions* and *Finance stability*, ii) Customer satisfactory degree: *Owners/Government & public satisfactory degree*, iii) Inner-business process: *Quality/Progress/Cost control* and *Internal communication & cooperation*, iv) Study & Growth: *Staff case, Project's innovative capability* and *Knowledge management*. He also proposed a total of 51 2nd class KPIs, with some of them having significant influence on international engineering projects.

Cha and Kim (2011) attempted to develop a framework to be used as an effective PMS for building construction projects in South Korea, focusing on the construction phase from the perspective of the construction company. They collected a number of potential indicators through a thorough literature review and case studies, which in turn were reviewed and revised by construction projects experts, resulting to 8 performance categories and a preliminary set of 27 KPIs. In order to inspect the initial list checking the validity of the candidate indicators and examine their measurability and representativeness, they conducted two preliminary survey investigations, carrying out in-depth interviews with selected experts. From this procedure, 6 categories serving as performance criteria, namely: *Cost*, *Time*, *Quality*, *Safety*, *Environment* and *Productivity*, and 18 final indicators were screened out. Based on the finalized 18 KPIs, Cha and Kim conducted an extensive survey in order to verify the established PMS and to quantify the individual project performance indicators, by calculating a weight for each indicator.

Ikediashi et al. (2012) developed a set of KPIs for measuring performance of D&B projects in Nigeria, aiming to examine their importance on performance outcomes and to ascertain the agreement level among key stakeholders on them. In their study, an initial set of 12 quantitative and qualitative indicators were firstly identified through literature review and were then rated with the descriptive research approach using a structured questionnaire and a four point Likert scale. The questionnaire respondents represented construction stakeholders such as client/contractor-based organizations. Their findings identified 8 KPIs consistently perceived as highly significant, which were: *Job cost reporting, Time performance, Resource management, Cost per Unit* and *Rework/Quality control* from the quantitative indicators and *Quality of work, Health & Safety* and *Motivation* from the qualitative indicators. The same 8 KPIs were found to be the most relevant and important indicators, although not in the same descending order.

Yeung et al. (2013), acknowledging that the basic problem with KPIs in construction management is their "lagging" nature, formulated a benchmarking model to evaluate performance of construction projects in Hong Kong, incorporating both leading and lagging KPIs. After compiling a list of 20 leading and lagging KPIs based on a two-stage, comprehensive literature review, they conducted a questionnaire survey with industrial practitioners, analysing the survey results with the Reliability Interval Method in order to determine the relative importance and weightings of the various KPIs. Their results identified 10 top-weighted KPIs, which were in descending order: *Safety/Cost/Time/Quality performance*, *Client's*

Table 1: Studies developing and implementing Performance Measurement Frameworks and KPIs for construction projects

Author(s) (Year)	Approach	Theoretical framework adopted	Project type	Implemented methodology	Life Cycle phases involved	Sustainability focus	Framework Notions			
							Dimensions/ Perspectives	Performance Criteria	Performance Indicators	
Chan, Scott & Lam (2002)	conceptual	multi-dimensional KPI	Design & Build	• literature – bibliography survey	•Design •Execution •Operation	• Social • Environmental	• Past: pre-construction • Present: construction • Future: post-construction	•<u>Objective</u> Time, Cost, Health & Safety, Profitabil. •<u>Subjective</u> Quality, Technical performance, Functionality, Productivity, Participants Satisfaction, Environm. sustainability	•Time/Cost overrun •Unit cost •Conformance degree to standards/technical specifications	•Construction time/speed •Injury/Accident rate •Total net revenue–Total cost •Resource input÷Given task •Sound/Air level
Cox, Issa & Ahrens (2003)	empirical	KPI	general construction	•literature review •questionnaire survey	•Design •Execution	• Economical • Social	-	-	•Quality control •Cost •Safety	•On-time completion •Cost÷Unit •Unit÷Man-hour
Chan & Chan (2004)	conceptual	KPI	general construction	• literature review • survey analysis	•Execution •Operation	• Social • Environmental	-	•<u>Objective</u> Time, Cost, Value & Profit, Health & Safety, Environmental Performance •<u>Subjective</u> Quality, Functionality, User expectation /satisfaction, Participants' Satisfaction	•Construction time/speed •Net Present Value •Environmental Impact Assessment score •Conformance degree to technical specifications	•Time variation •Unit cost • Per cent NETVAR •Accident rate •Number of complains •Participants satisfaction level
Yeung, Chan, Chan & Li (2007/2009)	empirical	KPI	partnering relationship-based	• conceptual KPI framework • Delphi survey technique with construction experts	•Execution •Operation	• Economical • Social	-	-	•Time/Cost performance •Trust & respect •Safety Performance •Innovation & improvements	•Top management commitment •Quality performance •Effective communications •Client's satisfaction
Li (2010)	conceptual	BSC KPI	international engineering	• literature – bibliography survey • SMART principles	•Execution •Operation	• Economical • Social • Environmental	• Finance • Customer satisfactory degree • Inner-business process • Study & Growth	-	•Profit potentiality •Finance stability •Government & public satisfactory degree •Internal communication & cooperation	•Finance operating conditions •Owners satisfactory degree •Quality/Progress/Cost control •Staff case •Project's innovative capability •Knowledge management
Cha &Kim (2011)	empirical	KPI	residential buildings	• literature review • interviews with selected experts • case studies	•Execution	•Social •Environmental	-	• Cost • Time • Quality • Safety • Environment • Productivity	•Defect frequency •Rework rate/frequency •Time savings •Safety to Cost ratio •Safety education •Site dangerousness	•Cost efficiency/effectiveness •Construction cost predictab. •Schedule efficiency/predictab. •Non-conform./Accident rate •Constr. waste/Recycling rate •Management/Labor productiv.
Ikediashi, Mendie, Achuenu & Oladokun (2012)	empirical	KPI	Design & Build	• literature review • questionnaire survey	•Design •Execution	• Economical • Social	-	-	•Job cost reporting •Quality of work •Resource management •Rework÷Quality control	•Time overrun •Health & Safety •Cost÷Unit •Motivation
Yeung, Chan, Chan, Chiang & Yang (2013)	empirical	KPI	general construction	• literature review • questionnaire survey • RIM weighting assessment	• Inception • Design • Execution • Operation	• Social • Environmental	-	-	•Safety/Cost performance •Planning effectiveness •Functionality	•Time/Quality performance •Client's/End users satisfaction •Communication effectiveness •Environmental performance
Langston (2013)	conceptual	KPI	general construction	• PMBOK knowledge areas • theoretical tetrahedron model	• Design • Execution • Operation	• Social • Environmental	-	• Scope • Cost • Time • Risk	•Value •Speed •Complexity	•Efficiency •Innovation •Impact
Maya (2016)	conceptual	BSC KPI	building	• previously developed model • application in a number of building projects	•Execution	• Economical • Social	• Financial • Customer • Internal process • Learning & growth	-	•Profitability •External/Internal customer satisfaction •Planning effectiveness	•Cumulative profit •Productivity •Human resource management •Human resource development

satisfaction, Effectiveness of communication, End-user's satisfaction, Planning effectiveness, Functionality and *Environmental performance*. They finally compiled a Composite PI to serve as a tool for evaluating and improving construction projects' performance at different stages of the project LC, namely the pre-planning, planning, designing, construction and commissioning phases.

Langston (2013) attempted to develop a 3-D project performance integration model, at different LC stages, including the 10 existing PMBOK's knowledge areas and advancing an 11th one of environmental management, to upgrade the importance of sustainability. Comprising four core project constrains (scope, cost, time and risk), suitable for objective measurement, he proposed six primary, generic KPIs integrated in a framework in the form of a tetrahedron, where the base reflected the classical "Iron Triangle" and the apex represented risk. The four constraints were placed in the four vertices of the tetrahedron and the six KPIs were represented by the edges of the model, expressing the relationships between the constraints. The proposed KPIs were defined as *Value, Efficiency, Speed, Innovation, Complexity and Impact* and could be measured as ratios of the four constraints, while an overall KPI in the form of a project success index was also derived. Although the proposed model was considered relevant to any project type, Langston demonstrated its application by an example of a hypothetical residential/infrastructure project.

Maya (2016) examined the application of a balanced and integrated PMS in order to serve as a tool to measure and manage Syrian construction projects performance, selecting BSC as a framework and utilizing a number of performance goals and a balanced set of indicators, focused not only on results but also on processes. Depending on a previously developed BSC model, in order to use indicators suitable for the building environment in Syria, and reserving the proposed strategy map of the model, she ended up with 8 final KPIs: *Profitability, Cumulative profit, External/Internal customer satisfaction, Productivity, Planning effectiveness* and *Human resource management/development.* The BSC Designer Software was employed as a MIS for performance measurement and management, aiming to support the application of all the BSC's elements, such as objectives, measures, goals and initiatives. To demonstrate a comprehensive application of the proposed model, the largest construction company and main contractor for public Syrian construction projects was selected as a research case study, while four building projects, under construction at that time, were chosen as a sample among the company's projects.

The context and the characteristics of the previously reviewed studies are summarized in Table 1.

4. Comparison of reported studies and discussion

Table 1 reports the basic features of each study and more specifically the approach followed, the adopted theoretical framework, the construction project type, the implemented methodology, the project's LC phases involved and the emphasized sustainability areas. The table also presents the main structure of the framework developed in each study, namely dimensions or perspectives implemented, performance criteria included and the proposed performance indicators. In terms of approach, the studies reviewed are as much conceptual as empirical, referring mostly to general construction or building projects. The selected KPIs basically originated from literature review, combined in some cases with questionnaire surveys with construction experts, implementing techniques like the Delphi method to address weights.

LC analysis of the presented studies suggests that PM in construction projects is drifting from the narrow limits of the Execution phase, representing the construction itself, and is gradually extending to the Design and Operation phases as well. Nevertheless, the majority of the studies seem not to examine the entire LC of a construction project, from Inception to Demolition. Regarding the sustainability aspects emphasized, the social dimension of the "triple bottom line" is the one distinctly appearing in all the reviewed studies, basically expressed with KPIs measuring users', or public in general, satisfaction level. Economical or environmental dimensions are alternately addressed in different studies through relevant indicators of financial viability or environmental impact. However, very few studies appear to deal equally with all three sustainability dimensions.

The previously reviewed studies manifest that recent trends in construction projects' PM, as well as the related KPIs proposed, involve in a much higher level, on the one hand LC analysis and on the other sustainability-focused criteria and indicators. Such trends represent the consideration of sustainability principles and the increasing need to develop KPIs as tools to integrate sustainability criteria into the management of construction projects. Conclusively, modern PMSs developed for construction projects can be considered as holistic approaches in performance evaluation, including the above features.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)

July 2nd-4th, 2018, Colombo, Sri Lanka

Effective mentorship of new entry graduates in the construction industry: A Literature Review

Morena William Nkomo
(PhD Candidate, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Wellington Didibhuku Thwala
(Full Professor, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Clinton Ohis Aigbavboa
(Associate Professor, University of Johannesburg, Department of Construction Management and Quantity Surveying, Beit Street.,
2094 Doornfontein, South Africa *)*

Abstract

Mentoring is vital for all young employees entering the workplace. Despite the growing research on both sets of individuals, mentors and protégés, mentoring from the perspective of the organizational remain comparatively under reported. It is important to significantly analyze the concept and to emphasize the distinct elements of effective mentoring of new entry graduates, in the construction industry. The aim of this paper is to look at the experiences and problems contributing to effective mentoring of young graduate's construction employees within construction companies. This study will examine how construction graduates employees are mentored, who is supposed to mentor them and how effective and crucial mentoring can be used to enhance performance in the construction industry, which has become very competitive and difficult. It will look at the important potential negative outcomes or problems in mentoring.The paper focuses on how organisations view mentoring. The study is mainly a literature review with a special focus on the human resource management and leadership, the data used in the report is generally qualitative, based on the content analysis, case studies and historical data that discusses formal mentoring internal to the workplace which sustain on and off job learning. The results revealed the organisation current circumstances and the issues that are important to the HR function. Mentoring is primarily used to transfer tacit knowledge from those close to retirement to younger employees, foster the personnel development and create well being at work. The study will indicate whether or not young graduates' construction workers are they being motored or not, are they involved in any form of mentoring, within their construction companies and that communication skills, knowledge sharing, and correcting mistakes or giving negative feedback are important for an effective mentor in the construction industry and also that mentoring is an important tool that can enhance career and personal growth when conducted effectively.

Keywords
Construction industry, Graduates Employees, Youth Mentoring, Human resource development.

1. Introduction

Mentoring nowadays is a key element within national and local strategies for working with graduates, especially those who are viewed as 'socially excludedCouncil for Scientific Institute of Research Built Environment (2008). Few methodical evaluations of graduate's employees have taken place in UK to enable contrasts to be made between projects and with other forms of graduate's involvement. Hence, some groups of immature people are often constructed as a threat rather than as a resource for the future, meaning giving more information to the graduate, knowledge transfer in mentoring, they will know further than their mentors. Simultaneously concern about the vulnerability of graduates has led to exceptional levels of observation over some groups; this can be a black or white group. The construction industry is one of the major sectors which contributes to the economy of South Africa. It is for this reason that the industry has to keep up with producing the required quality; however the industry needs to be always filled with the people with enough skills to continue with the work. According to (Philips, 1983). The construction skills shortage has a negative impact on the construction industry. This impact affects the construction industry's performance and future developments of the construction industry. Mentoring is considered to be the oldest form of knowledge transfer (Brannen et al., al 1994).
Mentoring can also be used as a mechanism to communicate with those employees that are not open, in regard to their performance, to break down the ice in an employee. According to the Council for Scientific Institute of Research (Freedman, 1993), research report in South Africa, indicated that the absence of mentors and mentoring is an impediment to progress, advancement in the country in mentoring, meaning new development in the subject. The young person is constructed as in deficit – lacking skills, appropriate socialization, lacking appropriate parenting and subject to peer pressure.

1.1 Purpose of the Study

The aim of this paper is to contribute to a broader understanding of effective mentoring of new entry graduates employees. Mentoring programs plays a vibrant role in the enhancement of careers for construction graduates and increasing the productivity of the construction industry. A significant percentage of the workforce, within the construction sector is nearing retirement age over the next ten years. These employees have acquired a tremendous amount of knowledge about how things work, how to get things done and who to go to when problems arise. Losing their expertise and experience could drastically reduce efficiency, resulting in costly mistakes, unexpected quality problems, or significant disruptions in services and/or performance. This will impinge on graduates greatly, as to how will they work and perform their functions in an organization, and they are fully prepared with theoretical knowledge from the University not physical experience to do the work, as they need this knowledge and experience. In addition, faster turnover among younger graduate's employees and more competitive recruiting and compensation packages add significantly to the growing concern about the organization's ability to sustain adequate levels of performance. Effective mentoring of graduates employees is an interesting addition to the HRD (Human Resource Development) literature because many of the characteristics of an organization's, habitual approaches to employee human resources can't be easily changed.

1.2 Objectives of the study

- To investigate the mentoring of young graduates construction workers within organizations, whether they are being mentored or not.

- To determine experiences and problems contributing to effective mentoring of young graduate's construction employees within construction companies.

1.3 Methodology

The study is mainly a literature review with a special focus on effective mentoring of graduates employees current situation and the prospects for the future. The data used in the report is mainly qualitative, based on the content analysis, case studies and historical data.

2. Literature review findings

Skills shortage in the construction has been termed as one of the major setbacks of the construction industry. The government and other construction firms utilize mentoring programs which are used to train construction graduates. Many construction graduates participate in mentoring programs but don't acquire the required skills for them to start their careers even after completing the duration of this mentoring programs. The construction industry is one of the major sectors which contribute to the economy of South Africa. It is for this reason that the industry has to keep up with producing the required quality; however the industry needs to be always filled with the people with enough skills to continue with the work. According to (Philips, 1983) the construction skills shortage has a negative impact on the construction industry. This impacts affects the construction industry's performance and future developments of the construction industry. Mentoring is considered to be the oldest form of knowledge transfer (Brannen et al., 1994).
Mentoring is usually a formal or informal relationship between two people a senior mentor (usually outside the protégé's chain of supervision) and a junior protégé. Mentoring has been identified as an important influence in professional development in both the public and private sector in large and medium sized organizations. Mentoring as a form of strategic human resource management is an interesting addition to the HRD literature because it provides a mechanism of change for individual employees, within construction organizations. Having a powerful human resource development (HRD) organization is a worthwhile asset of companies, and an enterprise's efficiency is closely connected to human capital's managerial and developmental systems (Latagana, Dinu & Stoica, 2010). Human capitals play an important role in order to success an organization. Mentoring is about skill development and specialized knowledge transfer. Mentoring can also be used as a mechanism to communicate with those employees that are not open, in regard to their performance, to break down the ice in an employee. According to the Council for Scientific Institute of Research (Freedman, 1993), research report in South Africa, indicated that the absence of mentors and mentoring is an impediment to progress, advancement in the country in mentoring, meaning new development in the subject. The young person is constructed as in deficit – lacking skills, appropriate socialization, lacking appropriate parenting and subject to peer pressure.

Mentoring has been used for centuries as a way of helping younger protégés to advance, and, according to Darwin (2000) mentoring is presently at the forefront of strategies to improve workplace learning. Workplace mentoring is the most critical factor in worksite learning.Within the government and the private sector, mentoring is often a component of different types of development, including graduates career development and training programs in large and medium sized organizations. The major function of mentoring within these programs is to promote the protégé's development in specific areas and to facilitate successful completion of the program. While these mentoring relationships can produce positive developmental and organizational outcomes, both mentoring programs and relationships sometimes fail due to a diversity of causes and problems, for example lack of participation, no leadership involvement, poor planning, unrealistic expectations, and unclear goals. Today mentoring is commonly used in professional and managerial learning, but is relatively new as a means of supporting low paid trainees and apprentices doing certificate level qualifications.

Mentoring in the construction industry is a key element in construction work (Rogers, 2007). Few methodical evaluations of graduate's employees have taken place in UK to enable contrasts to be made between projects and with other forms of graduate's involvement. Hence, some groups of immature people are often constructed as a threat rather than as a resource for the future, meaning giving more information to the graduate, knowledge transfer in mentoring, they will know further than their mentors. Simultaneously concern about the vulnerability of graduates has led to exceptional levels of observation over some groups, this can be a black or white group.

2.1 Mentoring of graduates employees in the construction industry

More and more organizations are creating formal mentoring programs for various reasons. From increased morale to increased organizational productivity and career development, the benefits of an organization that actively supports mentoring are many. However, successful mentoring programs do not just happen. Organizations must first make a strong business case to establish why the organization should dedicate the time, attention and resources required to make a formal mentoring process work. According to a discussion document on restoring skills, compiled by the cidb(Construction Industry Development Board) along with the public works in South Africa the construction industry has experienced a major shortage of skills. The document further suggested that the cidb and the public works will create a document that will be used by construction firms to enhance the skills of their employees. According to the skills development summit in South Africa , there will be an establishment of new ways which will help in solving the shortage of skills in the construction industry.Mentoring is a key element in construction work (Ringen et al., 1995b). For example, it is very common on construction jobsites to have experienced workers, who oversee and mentor less experienced workers. However, the relationship between a mentor and his/her protégée´ in the construction industry may be different from the mentoring relationships typically observed in other industries, due to constantly changing work environment and crews, diverse and rapid tasks, and the short-term relationships that protégé's have with their mentors (Brotman et al., 1998) .

Mentoring relationships and formal mentoring programs have received accumulative attention in HRD and related literature over the past several years. Studies examining mentoring involvement have showed that up to two-thirds of employees have engaged in some type of mentoring relationship and that mentoring functions may be especially beneficial for employees because of the greater barriers they often face . Participation in formal mentoring programs has a variety of benefits for participants (Wanberg et al., 2003). Two of the most emphasized developmental benefits have been psychosocial and career advancement (Kram, 1985). In spite of increasing activity, few empirical studies have been performed examining outcomes of formal mentoring programs (Wanberg et al., 2003). Because of the substantial investment of time and energy on the part of organizations and mentoring participants, a better understanding of the presence or absence of formal mentoring program benefits would be an important contribution (Ragins et al., 2000).

2.2 Experiences and problems contributing to effective mentoring of graduate's construction employees

Although the benefits of mentoring stated in the literature, this does not prevent the possibility that mentoring relationships experience problems or negative outcomes, (Scandura ,1998). Initial research on social-psychological and interpersonal relationships notes that hostile incidents are common and often a neglected aspect of all relationships (Eby et al., 2000), these ranges from minor episodes, such as arguing, to serious incidents, such as physical or psychological abuse (Marshall,1994). In there study on negative mentoring experience revealed that protégés experience: Dissimilar personality and habits, mismatch within the dyad, self-absorption, work style, distancing behaviour, manipulative behaviour, inappropriate delegation of duty, intentional exclusion, credit taking, politicking, that is, self-promotion, technical income- petence, lack of mentor expertise, that is, interpersonal incompetency, sabotage of any efforts, general dys- functional, that is, bad attitude, personal problems and deception (Eby et al., 2000) . The authors advocated the need for further research in the area of negative mentoring in individual disciplines which might be different from one industry to another.

Problems or negative outcomes were rare between mentors and new knowledge workers, apart from dissimilar personality and habits which was seen as a problem or negative outcome indicating that this problem occurred fairly many times. General dysfunctional, that is, bad attitudes, personal problems for example, alcohol abuse, family problems etc. and deception, that is, not being truthful were never a problem to the new knowledge workers as there tendency was towards occasionally and never occurring (Agumba and Fester, 2010) . As per the finding it can be noted that if mentoring functions are adequately achieved then problems or negative outcomes are rarely experienced. Studies conducted by (Eby et al., 2000) and (Ragins et al., 2000) on dysfunctional mentoring relation- ships are not fully supported by this finding. The problems or negative variables in a mentoring relationship were obtained from related literature review, indicated (Nkado and Mbachu, 2002), that new knowledge workers occasionally experienced problems during mentoring. Dissimilar personality and habits, was seen as the main problem as it fell in the mean band between 2.60 - 3.40 indicating that it happens fairly many times. General dysfunctional, that is, bad attitudes, personal problems for example, alcohol abuse, family problems etc. and deception, that is, not being truthful were never a problem to the new knowledge workers as they fell in the mean band between 1.00 - 1.80.

3. Conclusion

The results from the current study indicate that communication skills, knowledge sharing, and correcting mistakes/giving negative feedback are important for an effective mentor in the construction industry. Retaining organizational knowledge in the face of changing workforce demographics is a complex challenge that requires simultaneously confronting the problems created by an aging workforce, a shrinking talent pool and increasingly restless employees. The results from this study can be used to augment current mentoring research and provide a starting point for mentor-assisted development in construction. This study is primarily the authors' description of the extensive learning and development process for graduate engineers that has been developed and embedded within Kentz Engineers and Constructors and other construction companies. However, some evaluative conclusions can reasonably be drawn. These are:

- In global engineering and construction skills shortages are real and the largest constraint on growth in the sector .Companies are competing for skills and within this context those seeking to be

- "Preferred employers" are investing in learning and development and the infrastructure to support career development. Engineering graduates are in a strong position when choosing employers.

Some of the best business decisions are made in times of scarcity when the value of resources becomes fully understood. Investment in the development of graduate engineers. All mentoring processes will remain works-in-progress if they are to remain relevant to changing business needs. It is to be hoped that the experiences related will resonate with others, and that lessons learned may have more general application, although every organization will have its own unique needs and circumstances. Among these lessons are that mentoring has lasting benefits, but that formal programme can fail to reflect this? An organization-wide mentoring process needs to balance the needs for uniformity with flexibility, needs to foster accountability, and needs to be refined in the light of practical realities. Above all it needs people who are committed to stick with the process in order to ensure its success.

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Literature Review of the applications of Artificial Intelligence (AI) in Construction Project Management

Chao Xiao
Department of Construction Management, East Carolina University, Greenville, NC, USA
Xiaoch17@ecu.edu

Amin K. Akhnoukh
Department of Construction Management, East Carolina University, Greenville, NC, USA
akhoukha17@ecu.edu

Yang Liu
i.D BIM Tech LLC, College Station, TX, USA
yang-liu@idbimtech.com

Abstract
The application of Artificial Intelligent (AI) has increased in the field of construction project management in recent years, mostly due to the development of high-performance computer or robot and the potential to improve construction management efficiency. To achieving a comprehensive understanding of the research work on this subject, this paper conducts a literature view and content analysis of existing literatures on AI application in construction project management field focusing on the last decade. The authors selected the articles based on different category of AI technology and published journals with an impact factor higher than 1.0. The search resulted in 68 articles, which were then categorized into five categories to systematize the research conducted over the years. They are construction productivity management, construction safety and health management, construction performance management, construction claims and litigations, and construction logistics and site planning. The authors then analyze the selected articles that are most representative and influential from each category based on their citation and pertinence to their field. This review concluded the current trends of AI application in construction project management and further identified the gaps and limitations of the existing studies which could lead the direction of future research.

Keywords
Artificial Intelligent, Construction Project Management, Neural Network, Computer Vison, Productivity Management, Safety, Construction Performance

1. Introduction

Comparing with the manufacture industry, construction industry as one of the pillar industries has its own characteristics. Due to the nature of construction industry and its tasks, it is highly competitive, risk-averse, very complex tasks, unique to each individual project, heuristic problem-solving need. In respond to these unique features, it has become critical to improve the performance, safety and sustainability of construction in general. To successfully accomplish a construction project, project management plays a critical role. To manage a construction project in a high efficient manner, construction managers and management teams have already developed and drawn on the experience of many different theories and techniques. For this reason, Artificial Intelligence (AI) starts to catch construction professionals' attention and soon becomes a suitable tool in recent years to benefit construction project management.

AI techniques has already been adopted in many fields, such as face recognition, fraud detection, detect vehicle and pedestrian, on-line product recommendation and advertisement. In general, AI is the ability of a digital computer or computer-controlled robot to perform tasks commonly associated with intelligent beings. The term is frequently applied to the project of developing systems endowed with the intellectual processes characteristic of humans, such as the ability to reason, discover meaning, generalize, or learn from past experience. It contains a wide range of disciplines and techniques, such as Machine Learning, Neural Network and Deep Learning. While there are many other research activities have conducted comprehensive reviews on AI techniques for construction application (Moselhi *et al.*, 1991; 1992; Chan *et al.*, 2009; Brilakis, 2012; Seo *et al.*, 2015), they either focus on a specific AI technique or a specific aspect of application field instead of providing an overview of AI applications in construction management. With the aim of providing the readers with comprehensive and sufficient knowledge of the current literatures and usages of AI in construction project management, we review herein the existing research in AI in construction management.

This study reviews current literature on AI applications in construction management: 1) to reveal the current trend of AI techniques; 2) to understand how these techniques are applied to address specific construction management related problems; 3) to identify commonly found research challenges and limitations; and 4) to provide innovative ideas, perspectives, and approaches that may help future studies.

2. Methodology

The literature search of AI application in construction project management was part of a comprehensive study of AI applied in general construction fields. This part mainly discussed the methodology of comprehensive literature search of AI application in all the fields in construction and its results that included the 68 papers used in this study of summarizing the implementation of AI in construction project management. Since no similar job has been done before, the comprehensive literature research reviewed publications on construction-related AI research until 2017 in use of the quantitative method of bibliometric analysis, with no fixed start date selected.

In the first step of this bibliometric analysis, we started with a key word search in Web of Science (WoS) database. "Construction" is used with "Artificial Intelligence", "Machine Learning", "Deep Learning", "Supervised Learning", "Unsupervised Learning", "Support Vector Machine", "Neural Networks", "Computer Vision", and "Natural Language Processing" together respectively as keywords in WoS "Topic". There were 2072 articles fit the selection criteria. Afterwards, an initial review was conducted to remove articles that are not in construction industry, duplicated, and do not apply AI techniques. After this first round of literature screening, 408 articles were selected. To ensure a more appealing bibliometric analysis and categorization to academic peers, articles published in journals with a WoS "5-year Impact Factor" less than 1.0 are removed, which resulted in 352 articles. To reveal the latest trend of applied AI techniques and their application fields with the bibliometric analysis, this review mainly focused on literatures published in the last 10 years between 2007 and 2017, 273 articles in 38 journals remain. This entire process along with it result is demonstrated in the following Figure 1.

After three rounds of literature screening, the following literature analysis was based on the 273 articles with higher impact that published in recent 10 years. The study first applied a generally used categorization method of bibliometric analysis on the literatures. Rather than using existing research themes or areas present in other studies for literature categorization, we proposed our own categories based on the articles' contents. Proceeding to the next step, the authors brought together the categories to restructure it into a systematic framework. Based on each article's content and domain, the selected articles are grouped into eight major categories according to their research objectives and application fields. The categorization result is shown in Table 1, along with the number of articles.

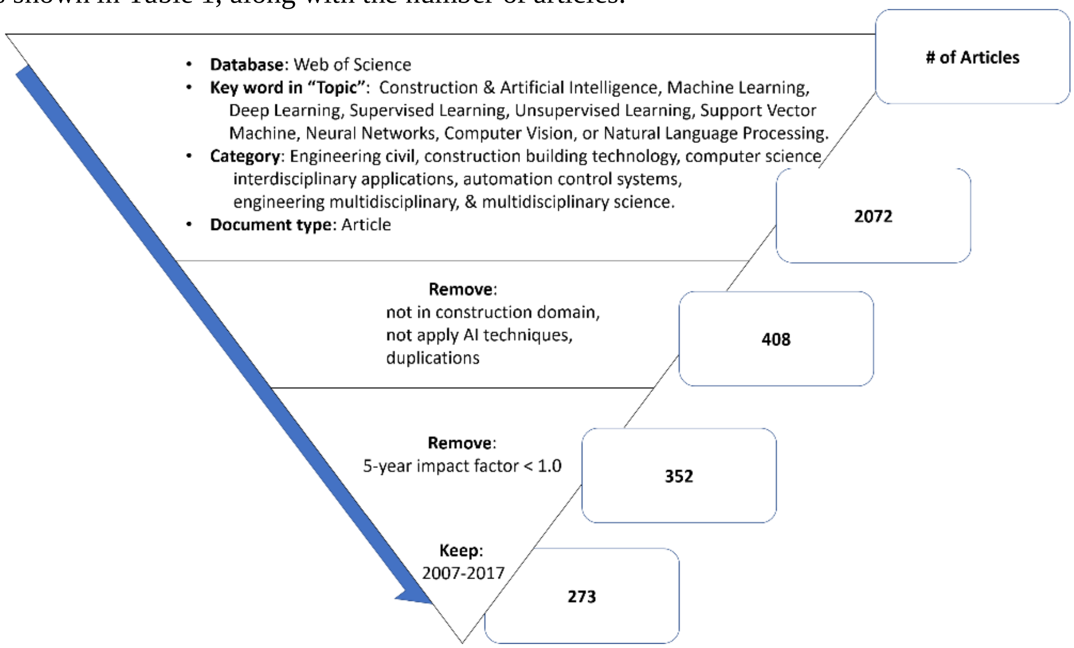

Figure 1: Literature Search and Screening Processes.

Table 1: Major Research Fields in Construction Domain Applying AI Techniques

Category	Num. of Articles
Construction Project Management	68
Construction Engineering: structure, material, and method	54
Estimation and Cost Control	42
Scheduling and Progress Control	15
Construction Business Administration	29
Construction-related Entity and Activity Recognition: imagery and sensing data	48
Project Document and Knowledge Management: textual data	21
Energy and Sustainability	8

Among the eight categories, construction project management was the primary field and the largest field of AI implementation in construction. To better explain AI could do for construction project management, this following paper focuses on the content analysis of application status, limitations and future trends of AI applications in this field. According to our selection criteria, there are 68 articles fall into the category of Construction Project Management. The articles are further developed into 6 sub-categories shown in Table 2. Among the sub-categories, "Productivity" was the most studied domain, while "Safety" becomes the most popular topic in the last three years.

Table 2: Sub-categories under Construction Project Management

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Total	%
Productivity	-	5	-	3	1	3	1	-	3	3	3	20	~29%
Safety	-	-	-	-	-	-	1	1	4	7	5	18	~26%
Performance	1	2	1	3	1	1	-	-	1	-	-	10	~15%
Claims & Litigation	2	-	-	1	-	1	3	1	-	1	-	9	~13%
Logistics & Site	-	1	-	-	-	2	-	3	1	1	-	8	~12%
Other	2	-	1	-	-	-	-	-	-	-	-	3	~4%

For the 68 articles about how AI applied in construction project management, not every single one was listed in the reference list in the end of this paper. The authors only referenced articles that we have directly used or we thought provide good overviews of the literature, by referencing both classic works and more recent surveys. We sincerely apologize if any scholar may feel slighted by their omission, and we are open to any feedback where someone feels that an idea has been misattributed.

3. Content Analysis

To discuss the results and provide a more qualitative analysis of the papers that discuss how to use AI techniques to benefit construction project management, the authors of this study proposed a sub-categorization structure summarized in Table 2 and used it to format the following content analysis. In the sub-categories descriptions, we have opted to describe and analyze the most representative and influential articles of the respective sub-category based on their citation and pertinence to their field.

3.1 Construction Productivity Management

Construction productivity management is a popular subject in the field of Construction Project Management. About 30% of the literatures studied the construction productivity using AI technologies. The majority of these studies focus on the approaches of applying AI techniques to measure or predict the productivity of construction crews, construction equipment, or certain construction processes based on collected or recorded data, while others focused on how to apply computer vision (CV) and machine learning (ML) to automatically analyze on-site productivity in real time.

To ensure the on-time delivery of qualified building products to the owner and its cost, it is essential to precisely estimate construction productivity. However, current practices heavily rely on historic data collected from various resources with inconsistent measurement and operators' personal experience, which may lead to a poor productivity prediction result. To address this problem, Song and AbouRizk (2008) developed a systematic process to collect data from both historic and on-going projects to train a neural networks (NN) to estimate labor productivity of future projects. By validating their work with actual data from a steel fabrication company, they concluded that NN was an effective approach to predict labor productivity with appropriate selection of NN's parameters and the NN algorithm. However, the requirement on large amount of pre-labeled/valued data brought difficulties on data collection. To avoid this shortcoming, in some of the latest studies, the researchers focused on comparing the performance among different NN algorithms, improving NN algorithms, and finding the most effective input variables to feed into the NN algorithms. Heravi and Eslamdoost (2015) further studied Multilayer Feed-Forward Back-Propagation NN with the data collected during the process of concrete foundation installation from two power plant construction projects to predict the construction productivity. The results have shown labor competence, poor decision making and motivation of labor were identified as the most influential factors for the construction performance. Recently, El-Gohary et al. (2017) studied the influence of 19 NN input variables at both project administration/management level and construction site level. To accurately predict crew productivity, Mirahadi and Zayed (2016) combined linguistic terms along with the numerical values together as input variables for NN algorithms. A hybrid approaching was developed, in which NN processed crispy values and FUZZY provided a systematic reasoning with fuzzy numbers, to accurately predict labor productivities with both qualitative and quantitative input variables. Different from above studies focusing on the crew productivity predication and management, many other scholars have paid their attention to predict other productivity relevant factors, such as earthmoving machinery effectiveness ratio (Schabowicz and Hola, 2008), production rate in tunneling project (Lau *et al.*, 2010), and productivity loss due to change orders (Cheng *et al.*, 2015 with the help of different NN algorithms and a hybrid AI system integrated FUZZY, SVM, and GA.

Analyzing and monitoring the productivity of on-going construction activities is as important as predicting it ahead of time. To overcome the drawbacks of the extremely time-consuming manually on-site observation by construction management personnel, (semi-)automatic and (near) real-time interpretation of imagery data collected from the jobsites becomes an increasing trend. Gong and Caldas (2010) designed and developed a semi-automatic video interpretation system combining CV and ML techniques to analyze the productivity and to detect abnormal scenario of certain construction tasks, including pouring concrete, earthmoving, installing scaffold, and hoisting. Recent studies have also focused on continuously analyzing the CV and ML techniques to improve the quality of the imagery data interpretation process. By adopting an active zoom camera and placing physical markers on target construction machines, Azar (2016) established a system which could detect and track specific pre-selected machines and collected task-oriented data more precisely. Soltani *et al.* (2017) suggested that knowing the pose of certain construction equipment can lead to a more accurate estimation of the time consumption on each operation state/phase. Thus, they developed a process which determined the 2D skeleton of excavators on video frames. Another contribution of this study was that it implemented synthetic images as the training images for the ML algorithm. It may inspire other researchers who have difficulties on obtaining enough training data.

3.2 Construction Safety and Health Management

Construction industry is one of the top contributors for workplace fatalities. Many construction accidents, which lead to enormous financial losses, are caused by poor safety performance. This has motivated extensive research activities to study the causes of injuries and unsafe behaviors, and applied AI techniques to develop various real-time safety monitoring systems to improve the practices of safety management.

To prevent unsafe behaviors or accidents on construction site, the ability to identify the causes for injuries and unsafe behavior is crucial for an effective construction safety management. AI techniques have been applied in many studies to detect the factors that affected construction safety climete. Goh and Sa'adon (2015) studied cognitive factors influencing an unsafe behavior of not anchoring a safety harness while working at height. With survey data collected from 40 construction workers, they compared Multiple Stepwise Linear Regression, NN, and Decision Tree techniques to explore the most influential cognitive factors that triggered the unsafe behavior. Their analyses revealed that 1) subjective norm was the key influencer for the unsafe behavior, 2) NN and Decision Tree were more suitable techniques to evaluate construction labor's cognitive factors. Taking advantages of large amount underutilized existing construction injury reports, several studies have established AI systems to analyze causes of diverse types of accident and to identify potential risks. Tixier *et al.* (2016; 2017) employed NLP to automatically transfer the unstructured injury reports to a structured accident database with 101 fundamental construction work environment attributes per report. They also compared two Unsupervised ML techniques to model the incompatibilities among the attributes. Based on experiments, NLP has found to be an efficient technique to quickly retrieve valuable data from injury reports with a high accuracy. Bayesian Network technique was also utilized in study the existing accident reports in some recent researches. Gerassis *et al.* (2017) focused on analyzing the causes of occupational accidents in embankment construction projects. Weka, a ML software (Hall *et al.*, 2009), was adopted to analyze a database of 353 accidents and to select the key attributes in these accidents. Then, the key attributes were quantified to analyze the causes of different accidents using Bayesian Network.

Monitoring on-site safety circumstance in real time is also an essential task that can help site manager proactively prevent injuries and identify potential threatens. While combining with ML techniques, computer vision and accelerometer were found to be efficient tools to automatically recognize unsafe behaviors in real time. Kim Hongjo and his colleagues (Kim *et al.*, 2015) introduced a hybrid AI model combined with computer vision and fuzzy inference techniques to monitor struck-by accidents and to improve on-site working practices. CV techniques were used to recognize construction workers and equipment from captured videos and calculate two risk factors: proximity and crowdedness. Then, the fuzzy inference was adopted to assess the on-site safety level based on both risk factors. Besides video camera and RGB-D cameras used in computer vision, accelerometer and the heat strain were also used to capture labor's motion data in recent studies. Lim *et al.*(2015) implemented accelerometer in smart phones to collect labor's three-axis acceleration streams, and applied 579 sets of processed datasets to train a NN classifier that recognized near miss slip and trip from normal walking events. An advanced portable light-weight wearable sensing system named Inertial Measurement Units (IMU) that integrates accelerometer, gyroscope and magnetometer together was then also utilized to capture labor's motion features and monitor unsafe behaviors in the study conducted by Yang *et al.*(2016). With the motion data collected at 17 body joints by the IMU based motion sensor, Chen *et al.*(2017) built a SVM multiclass classifier to detect 6 awkward postures from normal postures. Yi *et al.*(2016) constructed a heat strain (measured by Rating of Perceived Exertion, RPE) prediction model based on back-propagation NN technique monitoring the site condition with temperature and labors heart beats to protect labors who work in hot and humid conditions.

3.3 Construction Performance Management

As a construction project proceeds, measuring construction performance can help construction management team and project owner evaluate if their objectives are met. AI has applied in this research field to monitor the project performance dynamically, to identify causes for performance failure, and to measure the performance of other related activities which may influence project success, such as rework, construction management services in design phase, and pre-project planning.

Construction site and its surrounding environment keep change as project processes; thus, a good project performance prediction system should also be able to predict the performance dynamically. Ko and Cheng (Ko and Cheng, 2007; Cheng et al., 2010; 2012) developed several hybrid AI models for the above purpose by taking the progressive environment into account. As the ability of CV that could (semi-)automatically analyze images and video been noticed in construction industry, there are also numbers of researcher considered CV as a potential tool to monitor on-site project performance in real time. Yang *et al.*(2015) reviewed previous studies on computer vision techniques in construction that have the potential be applied for performance assessment and monitoring, and outlined the research gaps and potential future research.

Instead of measuring construction performance directly, other research activities focused on the influence of certain activities on project performance and project success. Wang *et al.*(2009) established 20 performance indicators under 5 major categories for the evaluation of construction management service in design stage, and then developed a NN model to estimate owner's satisfaction degree using the indicators. Wang and Gibson (2010) investigated the relationship between pre-project planning and project performance. They applied Project Definition Rating Index score as the indicator to describe the level of pre-project planning. With this indicator, Back-Propagation NN and Linear Regression were compared to predict project cost and schedule performance. By examine the experiment results, pre-project planning measured by PDRI score has found to be positively related to project performance measured by cost and schedule growth, and NN showed a better performance over Linear Regression with their dataset collected from 140 projects.

3.4 Claims and Litigations: Occurrence and Outcome Prediction

Construction projects involve numbers of different participants with their own interest. Managing different interests and potential arguments is also an important content of construction project management. Claims and litigations may influence the success of a construction project significantly. To provide decision-support information for managing potential claims and litigations, many studies have tested various AI techniques to predict potential occurrences and results.

One of major research areas regarding AI applications in construction claims and litigations is to predict their potential occurrences. Many studies have shown the feasibility of applying AI technique to predict potential litigation. Chou and Lin (2012) and Chou *et al.*(2013) compared various ML algorithms and ensemble learning systems to predict dispute occurrence. The efficiency and effectiveness of applying AI to proactively predict potential occurrence of dispute was re-confirmed, while the performance of ensemble learning systems was tested to be more reliable than single models in terms of predicting disputes in Publish-Private Partnership projects. MLP Back-Propagation NN was also applied to predict not only the potential occurrence, but also severity of claims regarding time and cost in construction projects (Yousefi, *et al.*, 2016).

Besides predicting the occurrence of potential claims and litigations, scholars also predicted their outcomes by taking advantage of AI techniques. Successfully predicting the outcome of a litigation provides each party involved in the litigation with a strong decision-support tool to find potential resolution prior to the litigation process and even support the decision of whether or not to take the case to litigation. Chau (2007) developed a hybrid AI system combining NN with Particle Swarm Optimization to predict litigation results in construction projects. Arditi and Pulket (2009) also compared performance of Weka (Hall et al., 2009) with various ML techniques including NN, Case Based Reasoning and Boosted Decision Tree on predicting construction litigation outcomes. 38 case attributes and the litigation results extracted from 132 cases were used to train the prediction models; and then 12 cases were implied to the models to predict their litigation outcomes. The test results suggested that the hybrid model outperformed other ML techniques, while the quality of training examples contributed significantly to the predication performance.

3.5 Construction Logistics and Site Planning

Construction site layout and logistics planning is one of the essential components in construction planning, and could incomparably affect the project progress. The task of construction site layout planning is dynamic, multi-objective and uncertain as project proceeds. To deal with these characteristics, Xu and Li (2017) worked on a mathematical model with fuzzy random variables to describe a multi-objective optimization problem of minimizing the total cost of site layout while maximizing the distance between the high-risk facilities and the facilities that needed to be protected from hazard resources. Yahya and Saka (2014) tested another AI technique in the name of Artificial Bee Colony to enhance the multi-objective site layout problem of minimizing facility cost and safety hazard. Their model was tested to be robust and efficient while applied in two case studies, a residential building construction project and a private hospital construction project. To optimize the location of a tower crane in a jobsite and its operational cost, Lien and Cheng (2012; 2014) proposed an approach which integrated Bee Algorithm and Particle Swarm Optimization together. The integrated model was compared with each individual algorithm for both one crane and multiple cranes optimization problems. Results showed that the proposed integrated algorithm outperformed the other two algorithms for location optimization, but it was unable to optimize operational cost for multiple cranes. The method has also shown a superior performance for facility layout optimization comparing with several Evolutionary Algorithms.

In addition to site optimization and facility layout problems, AI techniques have also been applied to solve problems in many other fields to improve construction logistics and planning, such as material transportation system (Zeng *et al.*, 2014), construction resource localization (Soltani *et al.*, 2015) and machinery path planning system (Kuenzel *et al.*, 2015).

4. Conclusion

As seen from the precious analysis, AI application research has consistently grown in recent years since more sophisticated algorithms being proposed, more powerful hardware being invented, and more data being collected for the computer to learn. Nearly about 60% of the papers being published in the recent 5 years of the period under review, meaning that the latest five years were particularly productive in terms of applying AI relative techniques in the field of construction project management. Despite the higher number of publications in the recent years, the quality and complexity of recent papers are substantially high, meaning that AI study in construction is reaching advanced levels of maturity.

In the categorization process, the authors carefully analyzed the content of the 68 selected articles and categorized them into five different fields that AI applied in construction project management. The application field that had the highest number of published papers were: (1) Construction Productivity Management; (2) Construction Safety and Health Management; (3) and Construction Performance Management. Accordingly, these three fields can be considered as the main research trend of using AI to facilitate construction project management, with the Construction Safety and Health Management having the highest growth rate in the recent five years, main pushed by the technologies of computer vision, natural language processing and data mining.

Our analysis of existing AI application literature revealed that the subjects that can be considered as contemporary trends or as having potential are: the usage of AI to reduce safety hazard and to improve construction productivity; the development of AI-based decision support tools; create hybrid/integrate system that combines more than one AI technique for analysis purpose; increase the ability and accuracy of (semi-)automotive process of real-time construction information. However, some gaps or topics that have not been solved were identified in AI application literature as well, namely: the lack of large amount of proper training images and date for computer vision and other AI technique when they were used in construction management fields; and methods to auto process the exiting data from construction project without affect the construction action that is going on.

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A linear goal programming model for optimizing the usage of safety measures on construction sites

Ming-Fung Francis Siu
Department of Building and Real Estate,
Faculty of Construction and Environment,
The Hong Kong Polytechnic University, Hong Kong, China.
francis.siu@polyu.edu.hk

S. L. Tang
Faculty of Science and Technology,
University of Macau, Macau, China.
irsltang@gmail.com

Corresponding author's email address: irsltang@gmail.com

ABSTRACT

In Hong Kong, the construction safety performance was poor but has improved in the past 15 years because the Labour Department has made remarkable progress in promoting safety and health in the workplace. Through the establishment of safety legislation, enforcement of existing and new legislation, industry promotion, and staff training, the safety awareness of employers and employees has increased. For example, under the "Pay For Safety Scheme (PFSS)", the contractors are required to set aside a sum of money in their bills of quantities for implementing safety measures on site. However, the method to optimally utilize such a sum of money so the overall profit is maximized remains unaddressed. This research study proposes a linear goal programming model to determine the optimal usage of safety measures (i.e., optimally utilizing the sum of money set aside) for improving construction safety. The goals of the model are to maximize the profits of both the main contractor and the sub-contractor. The constraints denote the achievements of safety measures in the provision of safety officers, safety committee meetings, safety walks, welfare facilities, safety training, and safety auditing. This paper intends to present the framework of the model. In the future, a case study will be conducted in full scale by expanding the model using the actual collected data and available statistics, thus the optimum usage of safety measures in real practice will be determined.

KEYWORDS

Linear goal programming, optimization, safety measures, Pay For Safety Scheme, Hong Kong.

1. INTRODUCTION

In the Hong Kong construction industry, the accident rate per 1,000 workers dropped significantly from 82.5 in 2002 to 33.6 in 2017, according to the statistical data published by the Labour Department of Hong Kong (Labour Department 2017). The Labour Department has made remarkable progress in promoting safety and health in the workplace. Through the establishment of safety legislation, enforcement of existing and new legislation, industry promotion and staff training, the safety awareness of employers and employees has increased. One successful public sector initiative for improving construction safety performance is the development and implementation of "Pay For Safety Scheme (PFSS)" that was developed in 1996 (Works Branch 1996).

In Hong Kong, the traditional procurement method is commonly used as the project delivery method in the construction sector. The construction contract is usually awarded to the contractor who bids the project with the lowest price. Before the implementation of the PFSS, the sum of money paid for implementing the safety-related items was not measured and identified in the tender document. Therefore, the contractors are likely not to budget the safety measure items to maintain a low bid and hence the competitiveness of the bid. In 1996, Works Branch under the Development Bureau introduced the PFSS in government construction contracts. Under the PFSS, all payable safety items and measures related to safety management that a contractor should carry out are included in a separate bill of quantities (i.e., site safety section). This sum is approximately 2% of the contract sum. Safety measures such as safety officers, safety committee meetings, safety walks, welfare facilities, safety training, and safety auditing shall be provided. When contractors comply with each of these safety items and have been certified as satisfactorily performed, payment for these items will be made on a monthly basis (ETWB 2000).

For example, as given in Poon *et al*. (2008), a *safety officer* shall be employed for a construction site employing more than 100 employees in total to maintain workplace safety and educate workers about safety at work, according to Chapter 59Z of the Factories and Industrial Undertakings (FIU) regulation. The main duties of the safety officer are to advise the proprietor if the safety measures are adequately provided in the interest of the safety and health of persons, and to determine if there is any machinery, plant, equipment, appliance, or work process carrying on which is liable to cause the risk of bodily injury to any person. The *safety committee* shall be responsible for maintaining the safety standard at the project (site) level. The safety committee meeting is organized once per week. The safety officers of the main contractor and the safety representatives (usually of the same rank as safety officers of the main contractor) of the sub-contractor shall participate the meeting. During the meeting, the overall site safety conditions shall be reviewed; any unsafe site operational procedures shall be rectified; the site safety performance shall be reported and forecasted so as to improve safety conditions on site.

Besides, *safety walk* shall be performed once per week by the safety officers of the main contractor and sub-contractor, and sometimes together with the clerks of works. A comprehensive checklist is used during the safety walk for inspecting the job site. Regular inspections enable a review of workplace activities and the presence of any hazards in and around the site. *Welfare facilities* shall be provided for the well-being of the workers. For example, sheltered rest areas are to be provided for workers to prevent heat stroke by taking a rest; drinking water facilities are to be provided for workers in a clean and hygienic condition; shower facilities are to be provided for workers to take a shower so dust or any harmful substances can be removed from a person's body. *Safety training* shall be provided by the safety officers or trainers everyday throughout the project period. By taking this everyday training, the workers shall have a better understanding of risky conditions that their safety awareness shall be fostered. The worker shall take immediate remedial actions to eliminate any unsafe conditions and acts. Furthermore, *safety auditing* shall be conducted by a third party to identify the rooms for improvement of the safety measures used in the company. This auditing exercise is normally performed every half a year.

The merit of the PFSS scheme is to pay for those ingredients to promote the implementation of a safety management system in a contract. The quantity surveyors of the main contractor are allowed to set aside a sum of money in the bills of quantities for carrying out the safety measures on site. Usually, 2% of the contract sum shall be budgeted. Constrained by the sum of money (2% of contract sum), the contractors are granted the flexibility to price the schedule of rate of safety measures which shall be implemented on site. However, currently a main contractor prices and determines the schedules based on intuition. The analytical method to optimally utilize such a sum of money for maximizing the profit along the supply chain of sub-contractors remains unexplored.

Therefore, this research study proposes a linear goal programming model for determining the quantities/frequencies of safety measures, by fully utilizing the sum of money set aside for improving construction safety. The goals of the model are expressed to maximize the profits of both the main contractor (priority 1) and the sub-contractor (priority 2). The constraints are given to indicate the achievements (i.e., quantities/frequencies) of safety measures in the provision of safety officers, safety committee meetings, safety walks, welfare facilities, safety training, and safety auditing. In the following section, the mathematical model is proposed. Conclusion is then drawn by proposing the future research.

2. PROPOSED GOAL PROGRAMMING MODEL

In this section, a novel goal programming model is proposed to mathematically quantify the degree of achievement of applying particular construction safety measures by fully utilizing the bills (or the sum set aside) for safety measures such that the profits of the main contractor (priority 1) and the sub-contractor (priority 2) can be maximized. The mathematical model is expressed from Equation (1) to Equation (16). Equation (1) expresses the objective function, and Equation (2) through Equation (16) are the constraints (Tang 1999, Chapter 7).

Equation (1) denotes the objective function. The function maximizes the profits of both the main contractor and the sub-contractor. The main contractor's safety cost is defined as the main contractor's expense for applying the safety measures, while the sub-contractor's safety cost is defined as the sub-contractor's expense for applying the safety measures. Thus, the profit maximization can be expressed as minimizing the sum of the under-achievement of the safety costs of main contractor and that of the sub-contractor given as the variables $d^-_{\text{Safety cost (Main contractor)}}$ and $d^-_{\text{Safety cost (Sub-contractor)}}$ respectively. Notably, the parameters P_1 and P_2 correspondingly state the priorities of minimizing the safety cost associated with the main contractor and the sub-contractor.

$$\text{minimize } P_1 d^-_{\text{Safety cost (Main contractor)}} + P_2 d^-_{\text{Safety cost (Sub-contractor)}} \tag{1}$$

Equation (2) is the constraint expressing the amount of safety cost for budgeting main contractor's safety measures. Safety cost is charged by the main contractor to provide particular safety measures with particular quantities/frequencies. The provision of the safety measures includes a number of safety officers $N_{\text{Safety officers (Main contractor)}}$ at an unit rate of $C_{\text{Safety officers (Main contractor)}}$, a number of safety committee meetings $N_{\text{Safety committee meetings (Main contractor)}}$ at an unit rate of $C_{\text{Safety committee meetings (Main contractor)}}$, a number of safety walks $N_{\text{Safety walks (Main contractor)}}$ at an unit rate of $C_{\text{Safety walks (Main contractor)}}$, a number of safety welfare facilities $N_{\text{Safety welfare facilities (Main contractor)}}$ at an unit rate of $C_{\text{Safety welfare facilities (Main contractor)}}$, a number of safety training $N_{\text{Safety training}}$ at an unit rate of $C_{\text{Safety training}}$, and a number of safety audits $N_{\text{Safety audits}}$ at an unit rate of $C_{\text{Safety audits}}$. The variables $d^-_{\text{Safety cost (Main contractor)}}$ and $d^+_{\text{Safety cost (Main contractor)}}$ respectively give the under-achievement and over-achievement of main contractor's safety cost.

$$\begin{aligned}
&C_{\text{Safety officers (Main contractor)}} N_{\text{Safety officers (Main contractor)}} + \\
&C_{\text{Safety committee meetings (Main contractor)}} N_{\text{Safety committee meetings (Main contractor)}} + \\
&C_{\text{Safety walks (Main contractor)}} N_{\text{Safety walks (Main contractor)}} + \\
&C_{\text{Safety welfare facilities (Main contractor)}} N_{\text{Safety welfare facilities (Main contractor)}} + \\
&C_{\text{Safety training}} N_{\text{Safety training}} + \\
&C_{\text{Safety audits}} N_{\text{Safety audits}} + \\
&d^-_{\text{Safety cost (Main contractor)}} - d^+_{\text{Safety cost (Main contractor)}} \\
&= \text{Safety cost}_{\text{Main contractor}}
\end{aligned} \tag{2}$$

Equation (3) expresses the safety cost for budgeting sub-contractor's safety measures. Safety cost is charged by the sub-contractor to provide particular safety measures with particular quantities/frequencies. The provision of the safety measures includes a number of safety officers $N_{\text{Safety officers (Sub-contractor)}}$ at an unit rate of $C_{\text{Safety officers (Sub-contractor)}}$, a number of safety committee meetings $N_{\text{Safety committee meetings (Sub-contractor)}}$ at an unit rate of $C_{\text{Safety committee meetings (Sub-contractor)}}$, a number of safety walks $N_{\text{Safety walks (Sub-contractor)}}$ at an unit rate of $C_{\text{Safety walks (Sub-contractor)}}$, a number of safety welfare facilities $N_{\text{Safety welfare facilities (Sub-contractor)}}$ at an unit rate of $C_{\text{Safety welfare facilities (Sub-contractor)}}$. The variables $d^{-}_{\text{Safety cost (Sub-contractor)}}$ and $d^{+}_{\text{Safety cost (Sub-contractor)}}$ respectively give the under-achievement and over-achievement of sub-contractor's safety cost.

$$\begin{aligned}
&C_{\text{Safety officers (Sub-contractor)}}N_{\text{Safety officers (Sub-contractor)}} + \\
&C_{\text{Safety committee meetings (Sub-contractor)}}N_{\text{Safety committee meetings (Sub-contractor)}} + \\
&C_{\text{Safety walks (Sub-contractor)}}N_{\text{Safety walks (Sub-contractor)}} + \\
&C_{\text{Safety welfare facilities (Sub-contractor)}}N_{\text{Safety welfare facilities (Sub-contractor)}} + \\
&d^{-}_{\text{Safety cost (Sub-contractor)}} - d^{+}_{\text{Safety cost (Sub-contractor)}} \\
&= \text{Safety cost}_{\text{Sub-contractor}}
\end{aligned} \tag{3}$$

Notably, as mentioned in the previous section, the representatives of the main contractor and sub-contractor are required to participate in the safety committee meetings together at the same time. Thus, the frequencies of safety committee meetings in association with the main contractor and the sub-contractor must be the same, as denoted by Equation (4).

$$N_{\text{Safety committee meetings (Main contractor)}} - N_{\text{Safety committee meetings (Sub-contractor)}} = 0 \tag{4}$$

Similarly, the representatives of the main contractor and sub-contractor are required to participate in the safety walks together at the same time. Thus, the frequencies of safety walks in association with the main contractor and the sub-contractor must be the same, as denoted by Equation (5).

$$N_{\text{Safety walks (Main contractor)}} - N_{\text{Safety walks (Sub-contractor)}} = 0 \tag{5}$$

In addition, Equation (6) indicated that the total sum of the main contractor's safety cost and sub-contractor's safety cost is less than or equal to the 2% of the contract sum.

$$\text{Safety cost}_{\text{Main contractor}} + \text{Safety cost}_{\text{Sub-contractor}} \leq 2\% \times \text{Contract sum} \tag{6}$$

A number of the safety officers, which are hired by the main contractor and sub-contractor, are required on site. Equation (7) and Equation (8) give the constraints for determining the number of safety officers provided by the main contractor and sub-contractor respectively. In Equation (7), the number of main contractor's safety officers $N_{\text{Safety officers (Main contractor)}}$ is calculated by $\frac{N_{\text{Workers (Main contractor)}}}{100}$ where the parameter $N_{\text{Workers (Main contractor)}}$ represents the number of construction workers hired by the main contractor. That means the number of safety officers is calculated based on every 100 workers, as is stipulated in the FIU regulation. The variables $d^{-}_{\text{Safety officers (Main contractor)}}$ and $d^{+}_{\text{Safety officers (Main contractor)}}$ respectively give the under-achievement and over-achievement of the provision of main contractor's safety officers.

$$N_{\text{Safety officers (Main contractor)}} + d^{-}_{\text{Safety officers (Main contractor)}} - d^{+}_{\text{Safety officers (Main contractor)}} = \frac{N_{\text{Workers (Main contractor)}}}{100} \tag{7}$$

Similarly, as shown in Equation (8), the number of sub-contractor's safety officers $N_{\text{Safety officers (Sub-contractor)}}$ is calculated by $\frac{N_{\text{Workers (Sub-contractor)}}}{100}$, where the parameter $N_{\text{Workers (Sub-contractor)}}$ represents the number of construction workers hired by the sub-contractor. The variables $d^{-}_{\text{Safety officers (Sub-contractor)}}$ and $d^{+}_{\text{Safety officers (Sub-contractor)}}$ respectively denote the under-achievement and over-achievement of the provision of sub-contractor's safety officers.

$$N_{\text{Safety officers (Sub-contractor)}} + d^{-}_{\text{Safety officers (Sub-contractor)}} - d^{+}_{\text{Safety officers (Sub-contractor)}} = \frac{N_{\text{Workers (Sub-contractor)}}}{100} \tag{8}$$

The safety committee meetings shall be held once per week. Equation (9) constrains the number of safety committee meetings $N_{\text{Safety committee meetings (Main contractor)}}$ in association with the main contractor as $\frac{T_{\text{Project}}}{7}$, where the parameter T_{Project} represents the total project duration in calendar days. The variables $d^{-}_{\text{Safety committee meetings (Main contractor)}}$ and $d^{+}_{\text{Safety committee meetings (Main contractor)}}$ respectively denote the under-achievement and over-achievement of the safety meeting provided by the main contractor.

$$N_{\text{Safety committee meetings (Main contractor)}} + d^{-}_{\text{Safety committee meetings (Main contractor)}} - d^{+}_{\text{Safety committee meetings (Main contractor)}} = \frac{T_{\text{Project}}}{7} \tag{9}$$

Equation (10), similar to Equation (9), constrains the number of safety committee meetings $N_{\text{Safety committee meetings (Sub-contractor)}}$ in association with the sub-contractor as $\frac{T_{\text{Project}}}{7}$. The variables $d^{-}_{\text{Safety committee meetings (Sub-contractor)}}$ and $d^{+}_{\text{Safety committee meetings (Sub-contractor)}}$ respectively denote the under-achievement and over-achievement of the safety meeting provided by the sub-contractor.

$$N_{\text{Safety committee meetings (Sub-contractor)}} + d^{-}_{\text{Safety committee meetings (Sub-contractor)}} - d^{+}_{\text{Safety committee meetings (Sub-contractor)}} = \frac{T_{\text{Project}}}{7} \tag{10}$$

The main contractor shall hold the safety walks once per week. Equation (11) constrains the number of safety walks $N_{\text{Safety walks (Main contractor)}}$ as $\frac{T_{\text{Project}}}{7}$. The variables $d^{-}_{\text{Safety walks (Main contractor)}}$ and $d^{+}_{\text{Safety walks (Main contractor)}}$ respectively denote the under-achievement and over-achievement of the safety walks provided by the main contractor.

$$N_{\text{Safety walks (Main contractor)}} + d^{-}_{\text{Safety walks (Main contractor)}} - d^{+}_{\text{Safety walks (Main contractor)}} = \frac{T_{\text{Project}}}{7} \qquad (11)$$

The sub-contractor shall hold the safety walks once per week. Equation (12) defines the number of safety walks $N_{\text{Safety walks (Sub-contractor)}}$ as $\frac{T_{\text{Project}}}{7}$. The variables $d^{-}_{\text{Safety walks (Sub-contractor)}}$ and $d^{+}_{\text{Safety walks (Sub-contractor)}}$ respectively represent the under-achievement and over-achievement of the safety walks provision.

$$N_{\text{Safety walks (Sub-contractor)}} + d^{-}_{\text{Safety walks (Sub-contractor)}} - d^{+}_{\text{Safety walks (Sub-contractor)}} = \frac{T_{\text{Project}}}{7} \qquad (12)$$

The safety facilities shall be provided by the main contractor every day. Equation (13) calculates the number of safety welfare facilitates $N_{\text{Safety welfare facilities (Main contractor)}}$ as T_{Project}. The variables $d^{-}_{\text{Safety welfare facilities (Main contractor)}}$ and $d^{+}_{\text{Safety welfare facilities (Main contractor)}}$ respectively denote the under-achievement and over-achievement of the main contractor's facility provision.

$$\begin{aligned} &N_{\text{Safety welfare facilities (Main contractor)}} + d^{-}_{\text{Safety welfare facilities (Main contractor)}} - \\ &d^{+}_{\text{Safety welfare facilities (Main contractor)}} = T_{\text{Project}} \end{aligned} \qquad (13)$$

Similarly, the safety facilities shall be provided by the sub-contractor every day. Equation (14) calculates the number of safety welfare facilities $N_{\text{Safety welfare facilities (Sub-contractor)}}$ as T_{Project}. The variables $d^{-}_{\text{Safety welfare facilities (Sub-contractor)}}$ and $d^{+}_{\text{Safety welfare facilities (Sub-contractor)}}$ denote the under-achievement and over-achievement of the sub-contractor's facility provision respectively.

$$\begin{aligned} &N_{\text{Safety welfare facilities (Sub-contractor)}} + d^{-}_{\text{Safety welfare facilities (Sub-contractor)}} - \\ &d^{+}_{\text{Safety welfare facilities (Sub-contractor)}} = T_{\text{Project}} \end{aligned} \qquad (14)$$

Likewise, the safety training shall be provided every day. Equation (15) calculates the number of safety training $N_{\text{Safety training}}$ provided by the main contractor's safety officer as T_{Project}. The variables $d^{-}_{\text{Safety training}}$ and $d^{+}_{\text{Safety training}}$ denote the under-achievement and over-achievement of the safety training provision respectively. Usually sub-contractors do not provide safety training.

$$N_{\text{Safety training}} + d^{-}_{\text{Safety training}} - d^{+}_{\text{Safety training}} = T_{\text{Project}} \qquad (15)$$

Lastly, the safety audits shall be conducted every half a year. As shown in Equation (16), the number of safety audits of the safety management system is indicated as $N_{\text{Safety audit}}$. It is calculated as the total project duration divided by 182 days. The variables $d^{-}_{\text{Safety audit}}$ and $d^{+}_{\text{Safety audit}}$ denote the under-achievement and over-achievement of the safety audits. Usually, sub-contractors do not conduct safety audits.

$$N_{\text{Safety audits}} + d^{-}_{\text{Safety audits}} - d^{+}_{\text{Safety audits}} = \frac{T_{\text{Project}}}{182} \qquad (16)$$

Based on the above mathematical model, the optimum number (quantities/frequencies) of safety measures can be determined. As such, the sum of money set aside for improving construction safety performance can be effectively utilized by maximizing the total profit of both the main contractor and the sub-contractor.

3. CONCLUSIONS AND FUTURE RESEARCH

This research contributes to the existing body of knowledge by proposing a goal programming model to mathematically determine the optimal number (quantities/frequencies) of safety measures, by fully utilizing a sum of money which is budgeted for the main contractor and sub-contractor to provide the required safety measures on construction sites under the "Pay For Safety Scheme (PFSS)" initiated by the Hong Kong Government.

The objective function of the proposed goal programming model is to minimize the under-achievements of safety costs of the main contractor and the sub-contractor while meeting the quantities/frequency requirement of applying particular safety measures as specified in PFSS. As such, the overall profit along the supply chain of contractors can be maximized. The constraints denote the achievements of the main contractor's safety measures in the provision of safety officers, safety committee meetings, safety walks, welfare facilities, safety training, and safety auditing, along with the achievements of the sub-contractor's safety measures in the provision of safety officers, safety committee meetings, safety walks, and welfare facilities. If there are more than one sub-contractor (sub-contractor 1 with priority 2), we can add to the model the second sub-contractor (sub-contractor 2 with priority 3), and so on.

A computer programme for the use of solving the goal programming model can be attained by using mathematical solvers such as Matlab, Cplex, or simply Excel Solver (if you have the Excel software on your computer, you will be able to solve the goal programming model). The inputs of the programme are the unit costs of the respective safety measures provided by the main contractor and sub-contractor, along with the amount of contract sum, the total number of workers on site and the duration of the contract. These quantitative values are used for solving the mathematical model. The outputs of the programme are the optimal quantities/frequencies of particular safety measures that shall be applied on site. In the future, a case study will be conducted in full scale by expanding the model using the actual collected data and available statistics, thus the optimum usage of safety measures in real practice will be determined.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Biological Cell Surveillance: Implication on Construction Cell

Mayur Shelke
University of Southern Queensland, Brisbane, Queensland, Australia; mgshelke@hotmail.com

Vasantha Abeysekera
School of Civil Engineering and Surveying, Faculty of Health, Engineering and Surveying, University of Southern Queensland, Queensland, Australia; vasantha.abeysekera@usq.edu.au

Abstract
The near flawless replication of the biological cells is often attributed to the Biological Cell Cycle Control Mechanism (BCCM) to develop a complex multi-structural functional element. Central to this success is the checkpoints and the surveillance mechanism of the cell. This paper, inspired by such perfection of cellular replication investigates this mechanism to develop further insights on replication of construction cells with a special focus on the biological cell surveillance mechanism. This led to the synthesis of three concepts, namely, *process stress*, *process memory* and *distress signaling*. Application of these concepts has been considered as a means of overcoming the quality problems encountered in a tunnel construction project. It is argued that the application of these concepts using the RGR framework during the tunnel slab construction could have mitigated the adverse quality issues by arresting the growth of defective construction cells.

Keywords
Distress signaling, process memory, process stress, Readiness-Growth-Rest framework, surveillance

1.0 The Context
The Biological Cell Cycle Control Mechanism (BCCM) and its role in ensuring proper cell division; and its implication on construction cell has been explored to give insight on managing construction (Abeysekera & Shelke, 2015a; Abeysekera & Shelke, 2017a). This is primarily based on the identification of construction cell, which like biological cells are replicated to construct a multicellular functional structure based on the design or the DNA. However, the similarity ends here because the biological cells achieve astounding accuracy in replication of cells, while the same cannot be said for the replication of the construction cell.

How does the biological cell achieve this? Inspired by such near perfect replication of biological cells, Abeysekera & Mayur (2017) have developed a new framework using the 'simile cum metaphor' approach. Referred to as the Readiness-Growth-Rest (RGR) framework, it is to be used for the replication of a construction cell replacing the traditional plan-control or the plan-do-check-act (PDCA) models.

2.0 Aims, Objectives and Methodology
The aim of the paper is to understand further the application of the RGR framework to construction work with specific reference to the surveillance and checkpoint mechanism used by biological cells during the cell division process. In order to achieve this the following objectives have been identified, namely, the study of the above-mentioned mechanisms in biological cells, synthesizing concepts relevant for the replication of construction cells, and the application of the synthesized concepts to a real project with documented quality (and time) problems. The project chosen is a tunnel project and focusses on the construction of the arched slab segment in a tunnel project that repeats along the longitudinal tunnel axis.

Primarily, this paper adopts the case study methodology, following literature study to understand the relevance of the surveillance and checkpoint mechanism employed in the biological cell. The first author was a participant as part of the quality management team so has firsthand information on the issues at stake. The paper also draws upon the earlier established role of the BCCM in cell replication and the notion that a construction cell can be considered as a biological cell, based on the *simile cum metaphorical approach* that resulted in the development of the RGR model for construction management (Abeysekera & Mayur 2017). Accordingly, the RGR framework (Figure 1) is considered for potential enhancements based on the developed concepts.

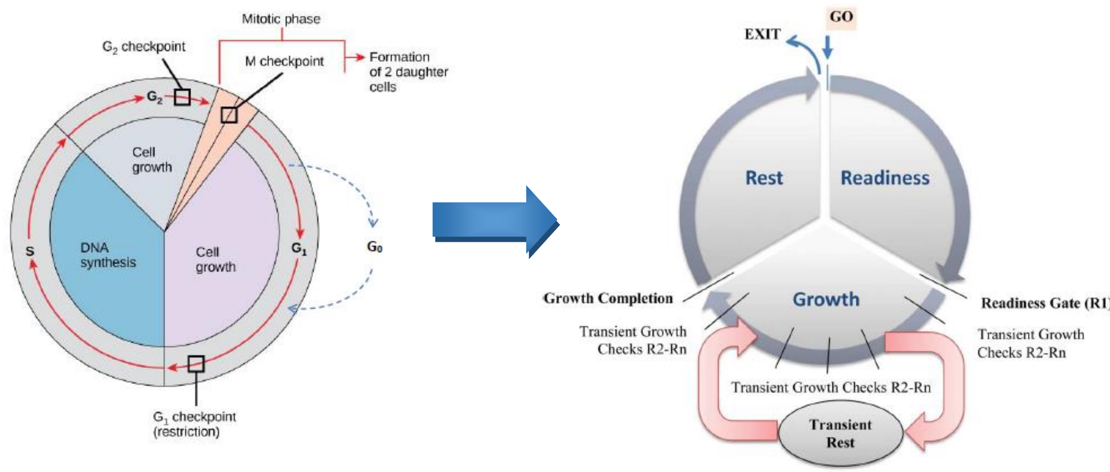

Figure 1: BCCM and RGR frameworks (Abeysekera and Mayur, 2017)

3.0 BCCM and the Readiness-Growth-Rest (RGR) frameworks

The BCCM is responsible for orchestrating the various processes of the cell cycle to achieve the sequential progression of the cell cycle (Abeyesekera andM. The cycle has two gap phases G1 and G2 between the S and M phases. In S phase, the DNA is replicated and in M phase, the cell division is completed resulting in two daughter cells having the design embedded in it for future replication. The fidelity of the cell reproduction depends on the regulatory mechanism controlled by the embedded design that ensures events of the cell cycle occur in the correct order and only after the preparations to start the next cycle is satisfactory. In other words, this readiness for cell replication is fundamental to success which is often taken lightly in construction. BCCM key features are summarized in The Table 1 given below (for more details, see Abeysekera and Mayur, 2017).

Table 1: Key features of the BCCM

Stages of Cycle	Phase of Cycle	Description
G0 (G-zero)	State of rest	Some cell may not be required to take part in replication, such cells are placed in G0 (G-Zero) state and remain in that stage until it receives signal to proceed.
G1 (Gap 1)	Interphase	Cells increase in size in Gap 1. The G1 checkpoint control mechanism ensures that everything is ready for DNA synthesis.
S (Synthesis)		Replication of DNA occurs in S-phase
G2 (Gap 2)		G2 phase-gap between synthesis (S) and mitosis (M) cell continues to grow. G2 checkpoint which will confirm the cell size, DNA replication quality and fix any identified problems before proceeding to the next phase, Mitosis for division.
M (Mitosis)	M-phase	Mitosis where the actual division of the cell will occur to yield two daughter cells. There is a checkpoint in the M stage which confirms the actual replication of the DNA is completed before the cell is split in two

As noted before, the RGR framework shown in Figure 1 is the conceptualized model for application to construction cell replication, inspired by the nearly perfect replication of cells (Abeysekera & Mayur, 2017). There are three main states viz. Readiness, Growth and Rest. The Readiness state will involve the design and development of the embedded design incorporating instructions and plans for execution of the cell-based construction. There is a gate to ensure 'Readiness' before transiting to the Growth phase to ensure satisfactory completion of Readiness state. The Growth stage is where cell construction commences at a pre-established rate and in order to ensure proper growth there are multiple Transient Growth Checks which could be driven by the standard hold points in the quality plans. The trigger for Transient arrest could be the threshold value set for parameters like the non-conformances recorded for the process in the Growth state. Such transient arrest would place the construction cell in the Rest state to address the issues before proceeding. Furthermore, the cells that are not ready for replication are also in the Rest state, until these are deemed ready for Growth. The surveillance system during the Growth state is seen as a key to ensuring the trigger for Transient rest enabling reexamination of the process, and eventually proceed further in an error free manner. The nature of the surveillance mechanism in biological cell is considered next. The developed insights based on this can be used to further refine this RGR framework.

4.0 Check Point and Surveillance Mechanism in Biological Cell

This section considers the working of the checkpoints and the significance of the surveillance mechanism in a biological cell. What is the surveillance mechanism used and what is the trigger for the checkpoint activation, and hence effective control over the cell division process? Organism are said to be communities of cooperating cell, and the corporation includes strict control on when cells divide to create a new cell. The consequences of breakdown in the controls in even a small number can be seen in cancer, a disease of uncontrolled cell division (eventually killing the organism) (Cassimeris et al. 2011, p. 674). This highlights the importance of the accurate operations of the surveillance mechanism and the checkpoints, given the disastrous consequences of lack of cellular control on cell proliferation.

4.1 Check Points Mechanism

The level of concentration of proteins within the cell are the basis of operation of the checkpoints. For example, the entry of cell into M phase is triggered by activation of protein kinase called as MPF (Maturation Promoting Factor). The MPF comprises two units namely the Catalytic Subunit, also known as cyclin dependent kinase [Cdk] and Regulatory Subunit. The Regulatory Subunit is the family of proteins called as cyclins (Karp, 2007). The activity of the Catalytic Subunit is dependent on the concentration of the cyclins. When the cyclins concentration is low the kinase [Cdk] is inactive and when the concentration is at the sufficient levels, the kinase [Cdk] is activated. Such transient activation allows the passage through the checkpoints. The concentration of cyclins rise and fall during cell cycle as a result of changes in the rate of synthesis and destruction of protein molecules. In mammalian cells at least 8 different cyclins and half a dozen different Cdks play role in cell cycle regulation. The passage through the checkpoints require the transient activation of Cdk by specific cyclins, as the cell passes through stages from one cell division to next. Thus, the Catalytic Subunit, appropriately also known as Cdk is activated or inactivated based on the concentration of specific cyclins, enabling the control of the checkpoints. Clearly, the checkpoints are controlled by the signals monitoring the concentration levels.

4.2 Surveillance Mechanism

Many signals registered at checkpoints come from cellular surveillance mechanisms inside the cell. These signals report whether crucial cellular processes that should have occurred by that point have in fact been completed correctly and thus whether or not the cell cycle should proceed. The checkpoints also register signals from outside the cell (Reece et al., 2011, p. 243). Three major check points in the various stages of cell cycle are identified in Figure 1 above. The surveillance mechanism in the Mitosis (M-Phase) where the actual division of the cell will occur to yield two daughter cells is considered which confirms the actual replication of the DNA is completed before the cell is split in two. This transmission of the DNA or the blueprint to the daughter cells is of utmost importance as this contains the codes for the very survival and accurate **replication** of the cell. According to Lambrus and Holland (2017), the cells have evolved certain precautions to preserve their DNA content during mitosis and avoid potentially oncogenic errors (leading to tumors). This is the cell proliferation outside of the cellular control mechanism, which is considered abnormal (Lax & Thomas, 2002) and can have disastrous consequences for the survival of the organism (Lax & Thomas, 2002; Martin, M, Ross, Jones, & Henderson, 1990; Simon, 1996).

Additionally to the checkpoints, recent observations have identified mitotic failsafe referred to as the mitotic surveillance pathway. This pathway triggers a cell cycle arrest to block the growth of potentially unfit daughter cells. This is activated by both prolonged mitosis and centrosome loss (Lambrus & Holland, 2017). This effectively curbs the growth of cells that do not have proper replication of the DNA. How such sensor conduct surveillance and activate the corrective action is considered next.

Based on data collected, Lambrus and Holland (2017) have determined that the gene responsible for DNA damage signaling, also plays an independent role to monitor the centrosome. The centrosome in the animal cell contains material that functions throughout the cell cycle to organize the cell's microtubules, (Reece et al., 2011, p. 235). The centrosome duplicates during G2 of Interphase and forms the mitotic spindle with the microtubules extending from it. This mechanism allows for the separation of the duplicated DNA (two sister chromatids) at each of the ends and facilitates the two liberated daughter chromosomes to form in the cell with each having equivalent and complete collections of chromosomes, marking the completion of mitosis.

The study by Lambrus and Holland (2017) points to at least three genes having indirect role in monitoring centrosome number. The loss in centrosome, as well as too much production of centrosome leads to cell cycle arrest. Such monitoring by multiple genes point to the redundancy built in this mechanism, which according to Stelling, Sauer, Szallasi, Doyle, and Doyle (2004) is the simplest strategy to protect against failure of specific component by providing for alternative ways to carry out the function that the component performs. Lambrus have deduced based on further findings loss in centrosome and too much production is indirectly detected through 'symptoms' associated with either loss or gain of centrosome. This is referred to as symptoms-based surveillance, described in next section.

4.3 Symptoms-based Surveillance

The idea of mitotic clock is introduced wherein the key defect observed in cells lacking centrosomes is that they are slower to assemble spindles and thus spend longer time in mitosis. An earlier pioneering study has demonstrated that prolonged mitosis surpassing a threshold duration is sufficient to trigger a cell cycle arrest in daughter cells despite the completion of an otherwise normal division. Lambrus and Holland (2017) have confirmed that the genes for centrosome surveillance also are responsible for mitotic timer functionality, thus there is possibility that centrosome loss triggers a cell cycle arrest by causing mitotic delay.

This is significant, because the surveillance has now introduced the element of time as a parameter. The completion time established for process is now monitored. Interestingly, one such delay in mitosis does not necessarily cause cell cycle arrest, however two such prolonged divisions will ensure cell cycle arrest. Lambrus and Holland (2017) propose that cell integrate '*mitotic stress'* over several divisions and also refer to '*memory model'* wherein the granddaughter cells can *'recall'* the stress from prolonged mitosis more than one full cell cycle earlier, and induce cell cycle arrest. This appears similar to the one of threshold parameters like non-conformance report (NCR) for inducing transient arrest of construction cell (Abeysekera & Shelke, 2017b). This threshold parameter of NCR has been further referred to in the conceptualized RGR framework to induce a transient cell cycle arrest to fix the process before proceeding further with construction (Abeysekera & Mayur, 2017).

The insights gained from the cell surveillance mechanism is used to synthesize concepts which can be applicable to the replication of the construction cell. This is considered next.

5. Synthesized Concepts

Three concepts have been synthesized for application to construction cell based on the surveillance mechanism employed in the cell. The cell appears to use process timer for surveillance and integrates the 'process stress' observed over the cell cycle activities and memorizes such occurrences before issuing signal to induce cell cycle arrest. The synthesized concepts are: (a) Process stress (b) Process memory and (c) Distress signaling to ensure 'process stop' based on symptoms

These concepts, while developed based on the growth of the mitotic phase, can be considered for the G-growth phase in the RGR framework (Figure 1). This phase is the actual construction phase, following the R or readiness phase. This is the phase of RGR framework, which can best utilize the concepts to monitor the construction process for stress and issue distress signals to induce transient state of rest.

The built in process timer is important for construction and activities which are delayed needs to investigated closely to determine the cause of such delays. While project schedule may resemble the timer or built-in clock, the efficacy of such timer or schedule is in question. Koskela and Howell (2008) have considered the adherence to a complete, priori statement of intent as illogical and instead advocated strategies that remain flexible and adaptive. Thus, the activities identified in the 2 week or 3 week look ahead offers more reliable 'feel' of ground situation and there needs to be analysis as to why the activities identified in the 2 week or 3 week look ahead plan has not been completed. Likely, any such identified delay is an indication of defects - in terms of interface issues, availability of men and material at the right place and right time, technical or process issues with the methodology etc. Any undue delay in achieving the completions of activities is an indication of process stress, which needs to activate the transient stop to the process. Review of plan and activities needs to be considered before proceeding further. This is well in line with the RGR model proposed by Abeysekera and Mayur (2017), wherein a transient state of rest is required for the process once triggered.

The integration of the process stress is a deliberate observation and record of process output not in line with the desired outcomes. For example, if there is a time limit based for an activity or productivity numbers like average concrete pour volume achieved, a record of such process values is maintained to determine the variation from the benchmarked values. This is what can be referred to as process memory, but memory alone is insufficient to ensure quality. While a singular deviation of time limit cannot form the basis to trigger quality alarm, such reoccurring events for the activity is likely to be symptomatic of potential quality issues. The time, especially for repetitive activities is likely to decrease given the effect of the learning curve, thus multiple record of variation of the process time may be indicative of process stress. This, in effect is variation of process parameter, measured in terms of time consumed for the activity which the system 'memorizes' for later use which in turn serves as the basis for initiating distress signal which may throw a process into a temporary state of rest. A case study is considered for application of such concepts.

6. Case Study Analysis-Slab Construction in Tunnel

The case of construction of tunnel slab in a large infrastructure project is considered. The first author was a participant in this case in the role of quality management. The Figure 2 below is depicting the process of concrete pour of 3200m^3 for slab construction in a tunnel.

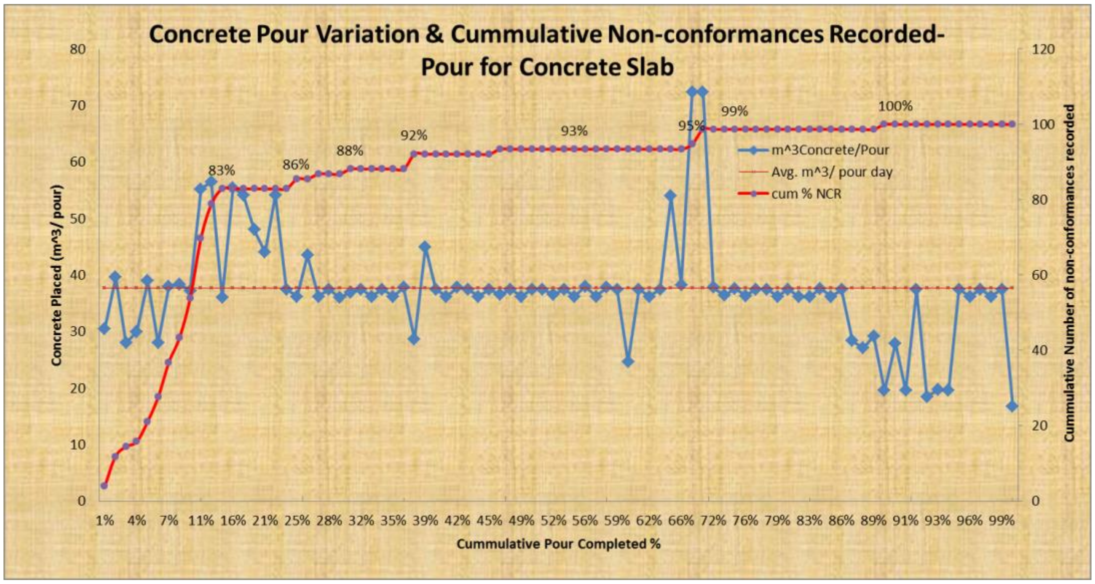

Figure 2: Plot of process for concrete pour volume and quality issues for tunnel slab construction

As evident, most of the quality issues ar recorded where the variation of the process is observed. The table 2 below depicts the occurrences of quality issues over the complete process.

Table 2: Process progression and quality issues

% Completion of job	Number of concrete pours	Number of Quality Issues or Non conformance	% QA Issues
First 25% of total concrete poured	19	65	86%
Between 26% and 50% of total concrete poured	22	6	8%
Between 51% and 74% of total concrete poured	19	4	5%
Final 26% of total concrete pour	26	1	1%
Total (3200 m^3 concrete)	86	76	100%

6.1 Analysis-Based on Surveillance Mechanism Concepts

An earlier case study of concrete pour variation for tunnel slab construction has shown remarkable co-relation with respect to quality issues recorded when the process variation in terms of average concrete pour volume varied from the average for the overall concrete pour process. Nearly 85% of quality issues were observed within the first 25% of the concrete pour (Abeysekera & Shelke, 2013; Abeysekera & Mayur, 2017). Could it be the lack of process stress integration and distress signaling for process stop contributing to this?

The process of concrete pour has progressed despite the quality issues, which were duly recorded. It seems in absence of process to consider such variations as ‘process stress’ the significance of the data in hand was not realized. There is also absence of distress signal mechanism to halt the process. The schedule for this activity can be considered as a timer because it has the duration, however, the actual record of the time required to complete the pour and related activity can be deemed as the record of the process stress. This is obvious, because a program schedule does not consider any quality related issues in it, neither in most cases it has provision for quality checks, while the actual record of time for the acivity has integrated the processs stress.

Positing that the record of the process time (time for concrete pour) could be the record of the process stress based on the time either exceeding or falling short of the average, then provides powerful tool of surveillance, wherein the process is not halted based on singular variation. Akin to the symptoms-surveillance employed by the cell, this can be a reliabel indicator to issue a process distress signal to induce a transient state of rest, giving an opportunity to re-set or evalute the factors causing such variation.

In this tunnel case, in hindsight it is clear that the progressive record of such ciritial process had signals embedded within it. This could be one of the major 'symptoms' to monitor. The identifcation of critical process and its record (is usallly avaialble) on most project but hardly analysed for such trigger given the lack of knowledge of the value such record holds. This is where the concept of process memory to analyse, compare and recall the construction cycle time to indicate likely issuance of a distress singal can abe useful.The surveillance mechanisms for symptoms in this case, the time taken for the process and the likelihood that such record also captures the process stress by capturing the variation, is highlighted by this developed concepts based on celluar surveillance mechanism. It is likely, triggering a transient state of rest then, as indicaed by the RGR framework to reset the process would have led to lesser quality issues encountered, post process reset.

The use of distress signal based on such anlaysis of process records to induce transient state of rest provides a new avenue to nudge the construction industry to consider the early signs for likely emerging quality issues with the process. A benchmark needs to be set for such distress signals, wherein a particular value is considered as a trigger to reexamine the process. In the RGR model, Abeysekera and Mayur (2017) have identifed the non-conformances recorded for setting the threshold to induce transient state of rest, this study has now indicated the process stress as an important indicator for setting the transient construction cell cycle arrest. Had the tunnel project, the awareness of such signals, and especially the distress signal to induce transient state of rest to review and reset the process, it is likely the number of quality issues would have been lesser. While there was surveillance, inspections carried out during the slab construction, the question is was this effective? Did it cause timely process review? From the Figure 2, it is clear that for the first 25% of the pour there was an increasing trend in quality issues. Likely, with evidence of process stress analysed in real time would have induced process review early to achieve stabilization.

The signals in a biological cell, issued, after it seems due diligence given the redundancy built into this mechanism are hard to ignore. The tunnel construction has lacked such distress signalling system for quality issues, which would have induced transient state of rest to address the process issues. Traditional tools like NCR induce a process hold, however this is post quality event. These synthesized concepts highlight the significance of the process records, process memory to decode the embedded signals and generate distress signalling. These would have provided an opportunity during the tunnel construction to evaluate the process, likely assisting in reducing quality issues, and thus achieve improvement in quality.

7. Conclusion and Recommendations

In most large projects, there seems to be progress records which are actually recording the time for activity completion. Creative use of such seemingly routine records with the identified quality issues and superimposing such data could provide a powerful surveillance tool. Such record over time, can be considered as the capture of the process stress and thus an indicator of the likely quality issues. The current quality practices in construction are well designed to keep record of quality events and recording the corrective actions taken, i.e. its strength appears in managing a quality event, rather than preventing quality event from happening, let alone signalling the likelihood of emerging quality issues. The project can use this as a tool as an early indicator of quality issues and be prepared to avoid quality issues, rather than marshal resources to fix the issues once they have occurred. There exists mechanism to 'hold' the process in the current quality management practice to inspect critical parameters before proceeding, however does it have the potency of the cellular signalling to stop the process? That such hold points or witness points for the process as prescribed in the quality plan are altogether missed is a likely event. This is where cellular distress signalling can be considered to ensure transient process stops, before quality event has occurred to re-examine the process before proceeding. The checkpoints in biological cells are unforgiving and a stop means 'stop'. This is one of the factors ensuring nearly perfect replication. In construction industry, it is an opportune time to consider the significance of signals to induce process stops at checkpoints to ensure there is reduction in quality issues.

The tunnel slab construction would have benefitted in hindsight, from application of above mentioned concepts. While credit needs to be given to the existing quality system to record quality events for such analysis, it is recommended that application of such developed concepts and the RGR framework for construction cell replication, Attempting to fix the quality issues appears to be a current trend, while cellular constuction allows for signalling likley quality events before occurrence.The RGR framework needs to be upated with the new trigger point like process stress. While threshold for the non-conformances is one of the trigger point, the process stress is likely to enhance the RGR framework to be more responsive to the construciton cycle replication in terms of monitoring for process stress and issuing distress signals. For long, the construction industry has carried on with activities to meet the program schedule, more often spending more time and money to fix the resulting defects. This is where the distress signaling based on process surveillance and output can be used to induce transient cell cycle arrest to reset the process however, the failsafe working of the checkpoints of biological cell based on surveillance signals, needs to be considered for adaptation in the construction industry. Further work here entails refinement of the RGR framework and development of robust methodology to ensure the relevance of such model to replication of construction cells, and thus by extension to construction industry.

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Initiating Smart City Concept for Sustainable Urban Development: A Litereture Review

Nimesha Jayasena
Department of Building Economics, University of Moratuwa, Sri Lanka
nimeshajayasena92@gmail.com

Harshini Mallawaarachchi
Department of Building Economics, University of Moratuwa, Sri Lanka
harshinim@uom.lk

K.G.A.S. Waidyasekara
Department of Building Economics, University of Moratuwa, Sri Lanka
anulk15@yahoo.com

Abstract
With the rapid urbanisation in the world, there is a requirement to achieve sustainability within urban development. Smart city concept directs urban development in to a strategic path to achieve sustainability in urban development. There are various definitions available for smart cities which represents various dimensions and characteristics of smart cities. Further, initiation of smart cities has become crucial due to the challenges faced by urban planners and developers. In recent years, many initiatives have developed under the smart city label in order to provide a response for challenges facing cities today. The understanding made up on the initiation of the concept of smart cities within any region would be fruitful to review in this nature. Therefore, as the primary step governs in this study, the fundamentals of smart city concept were reviewed to achieve the sustainable urban development as the main purpose. As the main approach adopted, a comprehensive review was conducted by using the twenty six (26) research projects in key literature. The concept of smart cities, the need of smart cities for sustainable urban development and the initiative factors of smart cities were finally encountered. As the key findings derived, the main and sub initiating factors of smart city concept for sustainable urban development were determined and presented through a conceptual framework. In response to the increasing use of the concept, this paper proposes to use the developed framework as a basis to understand the concept of smart cities for its flourishing initiation.

Keywords
Smart cities, Sustainable urban development, Initiative factors, Conceptual framework

1. Introduction

Cities become more and more complex every day and an almost endless list of expected characteristics for modern cities develops at an amazing pace. As stated by Mori and Christodoulou (2012), cities play a major role in economic, social and environmental aspects. However, they generate complex challenges for governments in means of uncontrolled development, traffic congestion, waste management and complicated access to resources and crime (Peris-Ortiz, Bennett and Yábar, 2017). Many cities due to rapid population growth face conflicting issues which include problems as over consumption of resources, inadequate number of services, and an increase in pollution. Achieving sustainable goals within the city is a major problem with the criticalities arises due to the above mentioned reasons (Bifulco *et al*., 2016). To overcome the problems generated by the urban population growth and rapid urbanization, there is an emerging necessity to make a city smart (Chourabi *et al.,* 2012). A smart city can be defined as "connecting the physical infrastructure, the IT infrastructure, the social infrastructure and the business infrastructure to leverage the collective intelligence of the city" (Harrison *et al*., 2010, p.2). A sustainable smart city develops in a manner to acquire the needs without compromising the ability of future generations to meet their own needs (Peris-Ortiz *et al*., 2017). Urbanisation increases the consumption of resources and in related emission which is an issue for sustainable development (Barles, 2010). Therefore, urban development projects aim sustainable development as a stated goal (Dale and Newman, 2009).

Urban sustainability focuses on technical issues, such as carbon emissions, energy consumption and waste management, or on the economic aspects of urban regeneration and growth (Tweed and Sutherland, 2007). With reference to Li *et al*. (2009), sustainable urban development is defined as "economic growth and efficiency, ecological and infrastructural construction, environmental protection and social and welfare progress" (p.134). As stated by Silva, Khan and Han (2018) "ability of a city to uphold the balance of eco system in all aforementioned aspects, while serving and performing city operations is known as the sustainability" (p. 698). As stated by Lazaroiu and Roscia (2012), smart city represents a society which consist of average technology size, interconnectedness, sustainability, comfortability, attractiveness and security .The concept of smart city has gained increasing importance because of enhancing the quality of life of citizens (Neirotti *et al*., 2014). Urban performance depends not only on the city's physical capital but also on the availability of human and social capital (Caragliu, Del Bo and Nijkamp, 2011). Further to authors, smart city concept is a strategic device to encompass modern urban production factors in a common framework. Hence, identifying the fundamentals of the concept of smart cities would be beneficial for any region where it can be used to make urban planners and developers aware about its initiation for sustainable urban development. Thus, as the main purpose of this paper, the fundamentals of smart city concept were reviewed to achieve the sustainable urban development. However, this is only a part of a research study in enabling smart cities in Sri Lanka: an integrated approach for building national level capacities of smart city development.

2. Initial Review of Literature

2.1 The concept of smart cities

Table 1 illustrates a comparison of evolution in the definitions of smart cities.

Table 1: Definitions of the concept of smart city

Year	Source	Definition
2017	Vaquero-García, Álvarez-García and Peris-Ortiz (2017)	Develops in a manner to acquire the needs without compromising the ability of future generations to meet their own needs
2017	Ramaprasad, Sánchez-Ortiz and Syn (2017)	"Smart city is a multidisciplinary concept that embodies not only its information technology infrastructure but also its capacity to manage the information and resources to improve the quality of lives of its people" (p.15)
2013	Bakıcı *et al*. (2013)	"Smart city implies a high-tech intensive and an advanced city that connects people, information and city elements using new technologies in order to create a sustainable, greener city, competitive and innovative commerce and a recuperating life

		quality with a straightforward administration and a good maintenance system" (p.139)
2012	Kourtit and Nijkamp (2012)	Smart cities are "the result of knowledge-intensive and creative strategies aiming at enhancing the socio-economic, ecological, logistic and competitive performance of cities" (p.93)
2010	Harrison *et al*. (2010)	"Connecting the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city" (p.2)

Governments have given attention to smart cities in their research and development projects. Even though, there is no common definition about smart cities (Bakıcı, Almirall and Wareham, 2013). As per the review stated in Table 1, it can be identified that there are different dimensions available for the smart city concept. Chourabi *et al*. (2012) identified that the concept of smart cities is used all over the world with different nomenclatures, context and meanings. Even though "smart city" gains wider importance with time, there is still confusion about the definition of a smart city (Albino, Berardi and Dangelico, 2015). This states the importance of identifying the fundamentals of smart cities. As stated by Han and Hawken (2017), success of smart cities should be viewed in terms of the ability to create high-quality places for everyday life.

2.2 Smart cities for sustainable urban development

In urban development, cities play a major role as it may effect on economic, social and environmental concerns in any country. Due to rapid urbanization and population growth, a city has become a crucial that need to be well planned and designed. Making smart cities has emerged as a solution for above concerns as a sustainable smart city develops in a manner to acquire the needs without compromising the ability of future generations to meet their own needs. In the urban planning field, the term "smart city" is often treated as an ideological dimension according to which being smarter entails strategic direction (Albino, Berardi and Dangelico, 2015). Cities nowadays face complex challenges in achieving goals regarding socio-economic development and quality of life. "Smart cities" is a response to these challenges which changes the path of urban development in to a strategic direction (Schaffers *et al*., 2011). Moreover, it includes individual development, institutional development, knowledge development and the development of associated decision support systems of cities (Agrawal, 2015).

2.3 Initiation of smart cities

From the definitions presented in Table 1, it was identified that different aspects of smart city concept is available. According to Giffinger and Gudrun (2010), there are six success factors of a smart city. They are smart economy, smart people, smart governance, smart mobility, smart environment and smart living. Chourabi *et al*. (2012) identified eight success factors of smart city initiatives which are namely management and organization, technology, governance, policy, people and communities, the economy, built infrastructure, and the natural environment. Nam and Pardo (2011) identified that technological factors, human factors and institutional factors as the three fundamental components of smart cities. By considering the above mentioned initiative factors, it can be identified that human factors, institutional factors and technological factors are important initiative factors within the smart city concept.

2.3.1 Human factors

A clever solution by creative people is required as an initiative factor for the development of smart cities which results sustainable urban development (Nam and Pardo, 2011). In the drive to become smart, cities will have to face certain challenges (Allwinkle and Cruickshank, 2011). A major challenge faced in the beginning of the drive to smart cities, is to adapt human resources for the change which can be mitigated by capacity building (Schaffers *et al*., 2011). With the current need of smart cities, Nam and Pardo (2011) identified the importance of people, education, learning and knowledge as they are the keys for success in smart cities. More over The smart people concept comprises various factors including affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism or open-mindedness, and participation in public life. Hollands (2008) also stated that the smart cities must seriously start with people and the human capital side. Giffinger and Gudrun (2010) identified that flexibility, creativity, open-mindedness, participation in public life, social cohesion and education as human factors required for a successful smart city.

2.3.2 Institutional factors

Governance of smart cities comes under the institutional factors. Institutional infrastructure of a smart city integrates public, private, civil, and national organisations to provide interoperation between services which results a more efficient, effective and a reliable service (Kitchin, 2014). Governance is important for the success and growth of smart cities because urban development and urban planning is based on governance with multiple stakeholders (Nam and Pardo, 2011). Collaboration, leadership, participation and partnership, communication, data-exchange, service and application integration, accountability, transparency can be identified as the factors that affect to smart governance under institutional factors (Chourabi *et al*., 2012). Participation in decision-making, public and social services, transparent governance, political strategies and perspectives are the institutional factors stated by Giffinger and Gudrun (2010). Policies of smart cities are also important for the initiation of the smart city concept because the policies can be used to identify the contribution for sustainable urban development (Yigitcanlar and Kamruzzaman, 2018). Moreover, it was identified that various regulations or accepted norms in their jurisdictions or communities is also important as fundamentals of smart cities (Allwinkle and Cruickshank, 2011).

2.3.3 Technological factors

Technological factors play a critical role in supporting decision-making, design, planning, development, and management operations of complex urban environments (Yigitcanlar and Kamruzzaman, 2018). Smart Cities base their strategy on the use of information and communication technologies in several fields such as economy, environment, mobility and governance to transform the city infrastructure and services. Information and communication technologies (ICTs) have been exerting a growing influence on the nature, structure and enactment of urban infrastructure, management, economic activity and everyday life (Kitchin, 2014). (Inter-) national accessibility, smart mobility and availability of ICT-infrastructure are considered as technological factors by Giffinger and Gudrun (2010). Accordingly, three basis factors of human, technological and institutional factors were encountered through the initial review of key literature. It was used as a basis to identify the initiative factors of smart cities concept for sustainable urban development as stated in Figure 1.

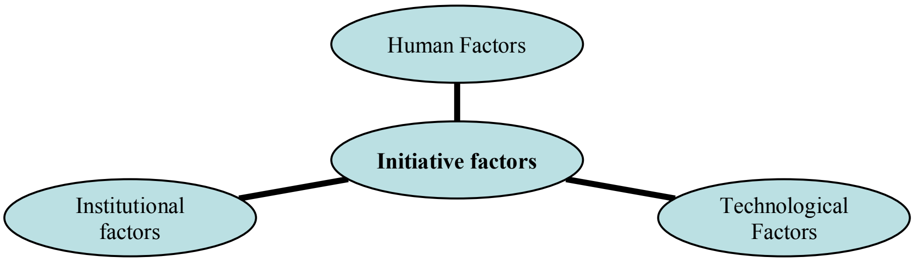

Figure 1: Initiative Factors of smart cities

3. Research Methodology

A comprehensive literature survey was carried out to identify the concept of smart cities and the fundamentals of the smart city concept for sustainable urban development. Twenty six (26) research projects in key literature were reviewed. Majority of the literature (81%) were obtained from recognised research databases of Emerald Insight (8%), Springer (15%), Elsevier (35%) and Routledge (23%) by using the search engines of Google Scholar, Science Direct and Emerald Insight. Only 19% of papers were reviewed from other sources including conference papers and websites as stated in Table 2.

The key literature were reviewed and analysed under the key headings of human, technological and institutional factors which were derived through initial review of literature. The key findings were determined by considering the majority of responses countered in review.

Table 2: The review criteria adopted

	Source				
Criteria	Emerald Insight	Springer	Elsevier	Routledge	Other (conference papers/websites etc)
Number of articles referred	2	4	9	6	5
% of Nos. of papers	8%	15%	35%	23%	19%
% of Total Nos. of papers		**81%**			**19%**

4. Initiative Factors of Smart Cities Concept for Sustainable Urban Development

The ten (10) key research projects in key literature were specifically reviewed and the initiative factors of smart cities concept for sustainable urban development were identified. Table 3 summarises the review of main and sub factors encountered.

Table 3: The review of initiative factors

Factors of smart city	Sources									
	1	2	3	4	5	6	7	8	9	10
Human factors					√	√	√			√

Flexibility						√	√			
Creativity						√	√	√		
Open-mindedness						√				
Participation in public life					√				√	
Social cohesion							√			
Education	√			√	√	√	√	√		
Ethnic plurality						√				
Institutional factors		√			√			√		
Governance					√		√	√	√	
Policies					√			√		√
Regulations		√						√		
Accepted norms		√								
Technological factors			√			√	√			√
Information and communication technologies	√		√	√		√	√	√	√	√
Accessibility			√		√	√	√			
Mobility	√		√			√	√		√	√

Sources: 1. Albino, Berardi and Dangelico (2015); 2. Allwinkle and Cruickshank (2011); 3. Bifulco *et al*. (2016); 4. Allwinkle and Cruickshank (2011); 5. Chourabi *et al*. (2012); 6. Giffinger and Gudrun (2010); 7. Lazaroiu and Roscia (2012); 8. Nam and Pardo (2011); 9. Schaffers *et al*. (2011); 10. Neirotti *et al*. (2014)

The initiative factors reviewed in Table 3 are described below.

4.1 Human factors

Caragliu, Del Bo and Nijkamp (2011) stated that human capital, education are important drivers for urban development. Allwinkle and Cruickshank (2011) also stated that education of the community initiates sustainable urban development which leads to smart cities. Flexibility, creativity and open mindedness creates a smart living environment which directs for sustainable urban development (Giffinger and Gudrun, 2010). Moreover, it was stated that ethnic plurality and education will create a link within the city which will be an initiative for smart cities.

4.2 Institutional factors

Allwinkle and Cruickshank (2011) identified that norms, regulations link members in the community and leads for a city to be smart. Governance, policies and regulations enables and directs the citizens to act sustainably (Nam and Pardo, 2011). Therefore for sustainable urban development, institutional factors play a major role. Chourabi *et al.* (2012) also stated that good governance can lead and guide a city to be smart which is a strategy for sustainable urban development. Furthermore Lazaroiu and Roscia (2012) revealed about the importance of smart governance in the path for a city to be smart.

4.3 Technological factors

As stated by Albino, Berardi and Dangelico (2015), high-quality and more efficient public transport are considered a key element for sustainable urban development. Authors further stated that new approaches related to urban services have been based on harnessing technologies, including ICT result in sustainable city development. However, it was revealed that ICT should be taken as an approach to enhance the quality of life. Bifulco *et al.* (2016) also identified that ICT applications, transportation systems, mobile devices allow people to participate and contribute to their urban development to be sustainable.

Accordingly, as the key outcome of this initial review paper, a conceptual framework graphically represents the factors and sub factors of the initiation of smart cities concept. The developed framework is presented in Figure 2.

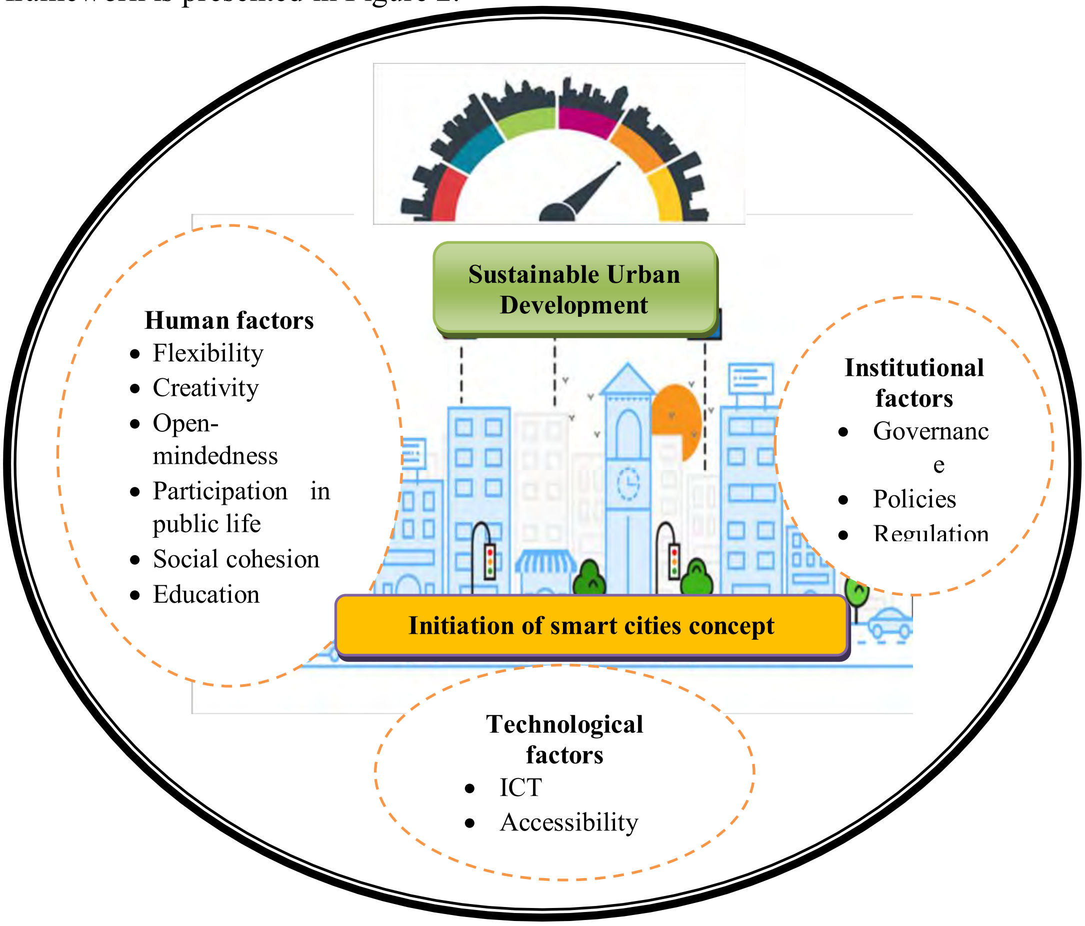

Figure 2: The conceptual framework

In the conceptual framework drawn in Figure 2, the bigger circle represents the concept of smart cities. The three (3) fundamental factors of the smart cities are represented by the three smaller circles within the concept. Sub factors of the human factors, institutional factors and technological factors were stated within each circle to achieve sustainable urban development through the successful initiation of the concept of smart cities.

5. Summary

With the rapid urban development, cities are facing many issues due to lack of sustainable practices. This leads a requirement for a city to be subjected under sustainable urban development. The concept of smart cities directs urban development to be sustainable. The requirement of smart cities initiates the necessity of identifying the fundamentals of smart cities. Three main factors were identified through the literature review as human factors, technological factors and institutional factors. Under the category of human factors, seven (7) sub factors were identified where four (4) sub factors were identified under institutional factors. Further, three (3) technological factors were also identified. The conceptual framework was developed as the major deliverable of this paper where it can be used as a basis to enhance the imitation of smart cities concept for sustainable urban development. Further, it would also be the first step in achieving the whole aim of the total study of enabling smart cities in Sri Lanka: an integrated approach for building national level capacities of smart city development.

6. Acknowledgement

This work was supported by the Senate Research Committee of University of Moratuwa under Grant SRC/LT/2018/17.

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A Study on Payment Issues Faced by Construction Consultants in Sri Lankan Construction Industry

H.M.A.K. Abeykoon, P.A.P.V.D.S. Disaratna, M.K.C.S. Wijewickrama
Department of Building Economics, University of Moratuwa, Sri Lanka
achiniabeykoonqs@gmail.com, vijitha.disaratna@gmail.com, mkcsw.mora@gmail.com

Abstract
Payment delays endure in the construction industry and prolong to be a key concern to industry practitioners. There is a social adherence that the contractors are the only suffering party from payment defaults in construction projects. However, construction consultants are also experiencing adversely from payment delays. There are different disciplines of construction consultants, categorized according to their scope of work which determines their mode of payments. The Sri Lankan construction consultants face payment issues which have not given significant consideration in research. Henceforth, this study aims to investigate different types of payment issues experienced by construction consultants and ways of minimizing them in Sri Lankan construction industry.

To accomplish the aim, initially, an extensive literature synthesis was carried out to identify construction consultants' fee payment practices and their related issues and causes. Consequently, qualitative research approach was followed steering semi-structured interviews which were conducted among practised consultants and clients in the local industry. The gathered data was analysed systematically via computer based content analysis. The topical study manifests highly impacted causes of fee payment issues, their effects and the best solutions to mitigate payment problems of construction consultants. Accordingly, major seven ways of mitigating consultants' fee payment issues were identified and amongst, negotiation is the most reliable mode to be used. Lastly, the research is recommending best practices which can be followed by clients and consultants to mitigate the fee payment issues of consultants in Sri Lankan construction industry.

Keywords
Consultants, Fee Payments, Issues, Mitigation, Sri Lankan Construction Industry

1. Introduction

Consultants are professionals, appointed by the client to perform expert tasks of a construction project through bridging the knowledge gap (Zou *et al.*, 2007). According to Nikumbh and Pimplikar (2014), shortage of specialized staff who are experts in latest technologies of the construction industry, shortage of supervisors who can be associated with a single project and to complete the project within short period are identified as reasons for the need of consultancy for a construction project (Nikumbh and Pimplikar, 2014). Construction consultants can be varying according to their scope of work. A typical project consultant team consists of architects, engineers, surveyors, town planners, quantity surveyors, estate surveyors and project managers (Anyanwu, 2013).

Ip (2012) explicated that there is a separate Standard Form of Agreement between consultant and client which clearly describes the responsibilities of a consultant in a construction project. Further to him, consultant's role varies in design stage, bidding stage, construction stage and in post-completion stage according to the established Agreement. As a remuneration for the responsibilities performed by consultants, client is obliged to pay a fee which is known as 'a consultancy fee' (Ip, 2012).

Generally, payment of a consultant is determined by including costs such as salary costs, social charges, statutory charges, overhead, reimbursable costs and a reasonable profit margin. Furthermore, these professional fees are calculated according to the lump sum fee basis, percentages fee basis, time basis or combination of them (Institution of Engineers Sri Lanka [IESL], 2012). Additionally, determination of consulting fee is based on the stage of the project, project complexity and scope of the services provided to the client (Consulting Engineers of British Columbia [CEBC] & Association of Professional Engineers and Geoscientists of British Columbia [APEGBC], 2009). However, in general context, there are lot of issues related to consultancy payment that should be given extreme consideration. Bestowing to Rashid (2007), payment issues can be identified as late payments, non-payments and under payments. The main reasons for these issues can be either due to client failures or consultant failures. Mostly, consultant failures like providing incomplete designs, lack of project knowledge and client failures like improper financial arrangements are highly exaggerating consultant payment issues (Haseeb *et al.*, 2011).

Aforementioned payment defaults adversely affect the whole construction business process, since each and every party in a construction project is connected to each other (Din and Ismail, 2012). Effects of consultants' payment issues to the construction industry and causes of them are not highly discussed under the Sri Lankan context. Therefore, it is an essential prerequisite to find out the issues and causes of consultants' payment issues and respective mitigation measures in the local construction industry. Henceforth, the study aims to investigate the causes for payment issues and ways of mitigating those in the Sri Lankan construction industry.

2. Contractual Provisions on Consultants' Payments

Construction consultant is an intermediary professional who conveys the client requirements to the contractor and the person who advise the client about the construction work (Tang *et al.*, 2009). Figure 1 shows the general classification of construction consultants in a construction project.

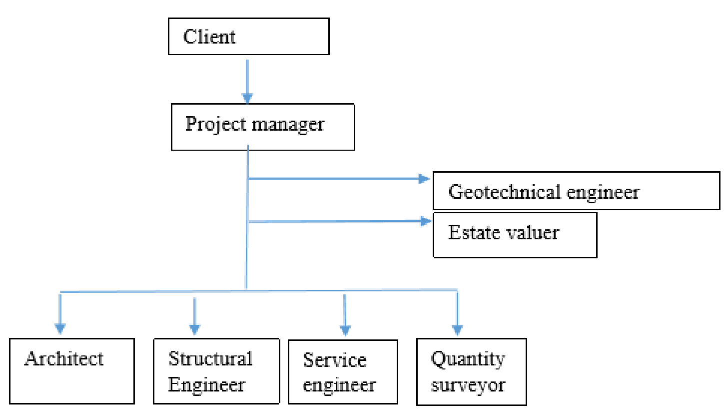

Figure 1: Consultants in a Construction Project

Source: (Adapted from Anyanwu, 2013, p.31)

To protect the rights of the consultant's payments, there are contractual provisions in FIDIC "white book", Client/ Consultant Model Services Agreement (Fédération Internationale Des Ingénieurs-Conseils [FIDIC], 1998). Table 1 illustrates the clauses in FIDIC white book which are related to construction consultants' payments.

Table 1: Clauses Related to the Construction Consultants' Payments

Clause	Description
Clause 30 – Payment to the Consultant	The Client shall pay the Consultant for Normal Services in accordance with the Conditions and with the details stated in Appendix C, and shall pay for Additional Service at rates and prices which are given in or based on those in Appendix C so far as they are applicable.
Clause 31- Time for payment	If the Consultant does not receive payment within the time stated in the Particular Conditions he shall be paid agreed compensation at the rate defined in the Particular Conditions compounded monthly on the sum overdue and in its currency reckoned from the due date for payment of the invoice
Clause 32- Currency of payment	The currency applicable to the Agreement is that stated in Particular Conditions.
Clause 34- Disputed invoices	If any item or part of an item in an invoice submitted by the Consultant is contested by the Client, the Client shall give prompt notice with reasons and shall not delay payment on the remainder of the invoice

Source: (Adopted from FIDIC, 1998)

3. Consultants' Payment Models in Construction Industry

According to the classification of IESL (2012), following are the different methods of deciding consultants' fee in Sri Lankan construction industry.

- Lump sum fee - More suitable when the scope and duration of the service clearly defined and unlikely to change. This includes salary costs, social charges and statutory charges, overhead, profit, any direct cost and any other negotiated costs.
- Percentage fee – Fee is calculated by multiplying cost related to separate work areas with their relevant percentage fees. Then, the total fee is derived by adding up those fees.
- Time based fee - This is mostly appropriate for large construction projects. It may be hourly rate, daily rate or monthly rate.
- Charge the market rate – Discover other consultants charge for their services, and charge a similar amount of fee is another way of determining the fee

4. Research Methodology

The qualitative research approach was selected for this study to conduct an exploratory in-depth analysis by gathering adequate information regarding construction consultants' payment issues. Semi-structured interviews were conducted to acquire comprehensive opinions about the consultants' fee issues in Sri Lankan construction sector. The interviews were carried among reputed consultants and clients in Sri Lanka and gathered data were systematically analyzed by computer based content analysis. Table 2 explicates the respondent profile of the study.

In this research different views were taken from construction consultants who were in different disciplines in the construction industry. Hence, consultants for the interview were selected from the consultancy firms, engineering firms and architect firms to get the different opinions. Furthermore, the interviewed clients were involved in construction sector and had sound knowledge on consultants' payment issues. All the selected interviewees represented the managerial levels of their firms, because deciding fee is considered to be an important strategic decision for an organization. Apparently, all the respondents except one had more than 10 years of experience in the industry and most of them had working experience in both private sector and public sector in local and foreign projects. Henceforth, the data gathered for this research study from those respondents were more reliable to derive final conclusions.

Table 2: Respondents Profile

Code on Interviwee	Designation	Years of Personal Experience	Type of Industry Group	Nature of Work	Number of Employees in the Company
C-01	Director	47	Consultant	Cost Consultancy	28
C-02	Managing Director	42	Consultant	Cost Consultancy	28
C-03	Director	24	Consultant	Cost Consultancy	12
C-04	General Manager	19	Consultant	Cost Consultancy	15
C-05	Senior Quantity Surevyor	08	Consultant	Cost Consultancy	22
C-06	Director	22	Consultant	Architectural	15
C-07	Architect	12	Consultant	Architectural	14
C-08	General Manager	14	Consultant	Architectural	24
C-09	Managing Director	12	Consultant	Engineering	18
C-10	General Manager	15	Consultant	Engineering	24
CL-01	General Manager	16	Client		35
CL-02	Chief Contracts and Commercial Manager	19	Client		60
CL-03	Project Manager	11	Client		15

5. Research Findings

5.1 Types of Consultants' Payment Issues

Mainly, there are three types of consultants' fee issues prevail in Sri Lankan construction industry. These issues are delays in paying consultant's fee, underpayments and non-payments. According to the findings, 80% of the interviewees conveyed that the most common issue in the industry is delays in payment. The clients' poor financial arrangements cause delays in paying fee and this adversely affects the newly established small consultancy firms. Moreover, underpayment situations are also common in local context, but not that much frequent as delay payments. Clients' unawareness about the scope of services provided by the consultants is the main cause for underpayments. Furthermore, when a new consultant enters to the industry, experienced clients provide them jobs with lesser fee and do not give a reasonable value for the work. Non-payments are also prevailing in the local industry but with minimum occurrences. Basically, clients are reluctant to pay when consultants' performances are unsatisfied and when the project is unexpectedly stopped due to any political, social or economical unrest.

It is interesting to highlight that, when comparing the possibility of occurring payment issues in local construction projects, all the respondents expounded that payment issues are extremely taken place in public projects than in private projects due to long lasting approval procedures.

5.2 Causes and Effects of Consultants' Payment Issues

The consultants' payment issues can be transpired due to client related causes, consultant related causes and external causes. Figure 2 clearly exhibits the consequences of consultants' payment issues which exaggerate from these different causes.

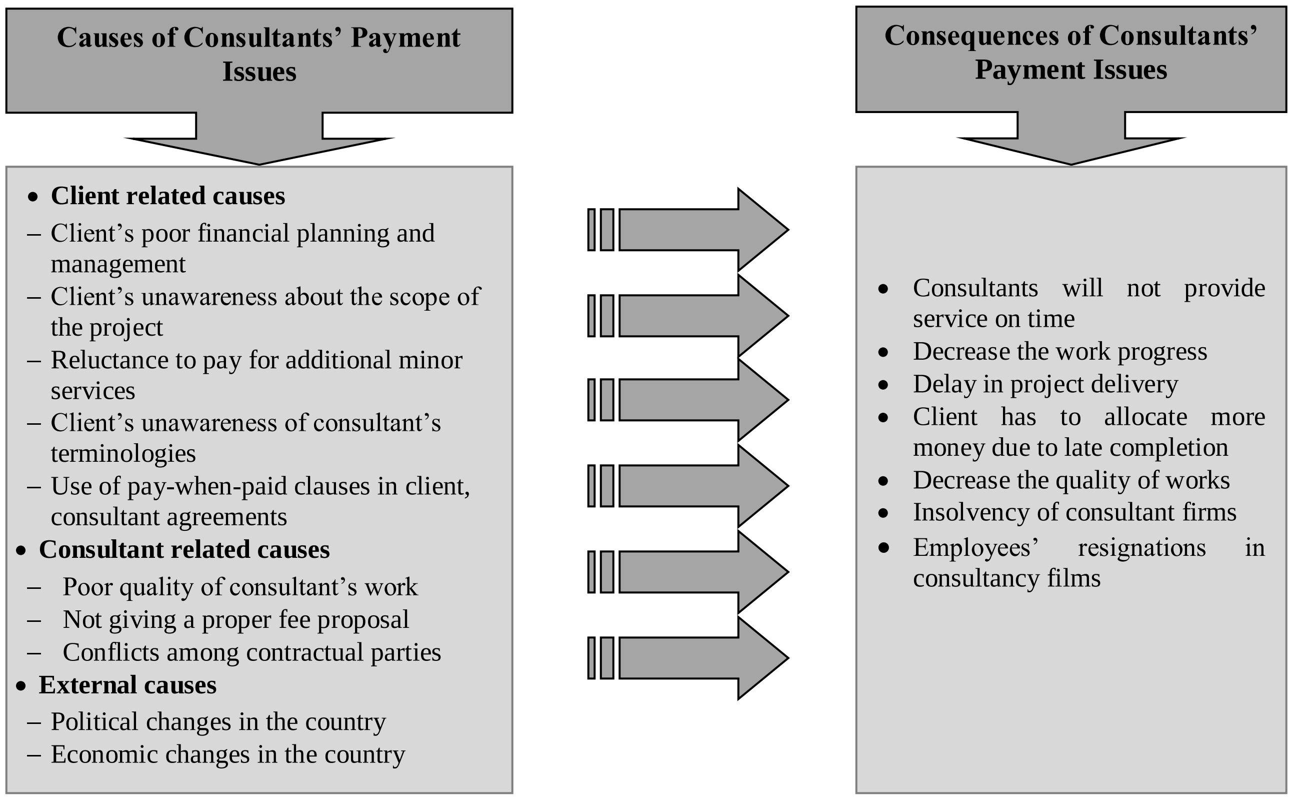

Figure 2: Causes and Consequences of Consultants' Payment Issues

5.2.1 Client related causes

The most influential client related cause is his poor financial planning and management. Generally, lack of government funds, delays in government payment approvals and inaccurate estimates of client's budget are the factors which catalyze the client's poor financial planning and management. Additionally, client's unawareness on consultants' terminologies and scope of the project also encourage the consultants' payment issues. Furthermore, in some situations, client is reluctant to pay the consultant for some minor works which are additional to the original contract. Moreover, there are pay-when-paid clauses included in client, consultant agreements which are unfavorable to the consultant parties.

5.2.2 Consultant related causes

Poor quality work of consultant is the most controversial consultant related cause which affects the payment issues. Generally, client will pay less or withhold the payments, when he is not satisfied with the work done by the consultant in poor quality. Furthermore, existence of improper agreement between client and consultant highly persuades the consultants' payment issues. According to the respondents, submission of an inaccurate fee proposal by the consultant when accepting a job and not confirming the fee before starting the work also cause the payment issues of consultants. Here, the fault is extremely with the consultants as they have not followed a proper procedure when agreeing a fee for a particular work. In addition, conflicts among contractual parties adversely impact the delays in payments or underpayments.

5.2.3 External causes

When there is a political change in the country, some projects especially the government funded projects are subjected to the termination. In such situations, all the payments of contractual parties will be ceased and subsequently, the consultants will directly be victims of this jeopardy. Moreover, economic recession in the country directly impacts the construction industry and its stakeholders. This will immensely affects the consultants of the industry since they have to face more difficulties to survive in the industry due to issues in payments.

The aforementioned sections clearly explain the causes which encourage consultants' payment issues in Sri Lankan construction industry. The effect of these payment issues will vary as the way it impacts on consultants, construction industry and other contractual parties which should be given more consideration.

5.3 Ways of Mitigating Consultants' Payment Issues

The best method to mitigate payment issues of consultants in the industry is the negotiation. All the research participants responded that this is the initial step which can be taken by consultant party or client party to resolve the payment issues. Similarly, taking an advance before commencing the works is a good strategy to mitigate payment issues which can occur in the future. Furthermore, obtaining a bank guarantee for payments will also minimize the risk of getting payments. Moreover, impacts of the late and non-payments can be solved through proper financial management of client. The current study also indicates that proper financial arrangement of client and estimating a precise budget before commencement will avoid difficulties of paying to the consultants in future. Further, not using pay-when-paid clauses in client-consultant agreement is a good precaution to avoid future payment defaults in advance. Preparing ad-hoc documents for additional services, using fee modifications, preparing proper client-consultant agreement at the beginning and conducting awareness programs for clients who do not aware the consultants' terminologies are the precautions which were expressed by the respondents in the current study. Convince the client about delay, outsourcing in house consultants and suspension of works are also can be considered as best strategies to tackle the consultants' payment issues.

FIDIC White book, Client/Consultant Model Service Agreement (1998) recommended a compensation for delayed payments of consultants. However, research participants complained that interest or compensation for delayed payments is not used in the Sri Lankan construction industry to tackle consultants' payment defaults. Thus, adhering to such well established form of contract is also a good practice to mitigate payments defaults of consultants.

Additionally, statutory adjudication or a similar dispute resolution mechanism can be used to handle payment issues of consultants. However, research participants, both clients and consultants explained that they are not interested to go for arbitration or litigation for resolving payment disputes since those are expensive and time consuming methods which will also damage their reputation.

6. Conclusions and Recommendations

There are multiple disciplines of consultants in the construction industry. Amongst, quantity surveyors, architects and engineers were selected for this research study as they are the major consultant groups in the industry. From the literature findings, it could identify that mainly time based fee; fixed fee and percentage fee are used in construction sector as payment models for consultants.

Moreover, the analysis of the findings expounded that delay of fee payment is a common phenomena in the industry when compared to the underpayments and non-payments. According to the views of research participants, payments are delayed mostly in government sector projects. There are client related causes, consultant related causes and external causes which highly affect the payment issues of consultants in local industry. These payment issues generate hostile effects like delays in the assigned tasks, decrease the progress and eventually total delay in the project. The final conclusions of the study manifest that consultants' payment issues adversely have an effect on the consultants, construction industry as well as other contractual parties.

However, there are many ways of mitigating payment defaults of consultants. The negotiation between parties is the key method used to minimize the impact of any payment issue. However, local practitioners were not keen on using arbitration or litigation to solve consultants' payment issues, since they are time consuming, expensive and damaging the reputation of organizations. Additionally, proper financial arrangement of client, taking advance before commencing the works and getting bank guarantee for payments are also reliable strategies to alleviate the payment issues of local consultants. Therefore, it is recommended for all industry practitioners to practice all these mitigation measures to eradicate the adverse impacts of consultancy payment issues.

7. Further Research Directions

This research was limited to the consultants who involved in traditional contracts. There is a difference of scope of services provided by the consultants in traditional contracts and design and build contracts. In design-build contracts, some consultants' paymaster is the contractor. Therefore, it is suggested to study the payment issues faced by construction consultants in design and build contracts as a further research.

From the current study, it was identified that there are client, consultant and external factors which raise the issues on consultancy fees in construction projects. Therefore, it is essential pre- requisite to study separately on how these factors encourage in ascending these issues in deeply and investigate the consequences and mitigation measures for each under separate researches.

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Leadership Assessment Tools that can be used in Managing Health and Safety in the Apparel Manufacturing Industry in Sri Lanka

Ekanayake B.J., Karunathilaka S.K.
University of Moratuwa, Moratuwa, Western Province, Sri Lanka
ra-biyanka@uom.lk, susilkumarakarunathilaka@gmail.com

Perera B.A.K.S
University of Moratuwa, Moratuwa, Western Province, Sri Lanka
pererabaks@gmail.com

Abstract
Developed countries have put forward specifications for assessing the commitment of their leaders to health and safety management. Other countries including Sri Lanka, unfortunately, have so far not been able to follow suit. Apparel manufacturing industry is a key industry in Sri Lanka, which demands a proper leadership assessment method to ensure better safety management in the industry. Therefore, this research was aimed to identify a leadership assessment tool to assess leadership commitment to health and safety management in the apparel manufacturing industry in Sri Lanka. Ten semi-structured interviews were conducted as a preliminary study among health and safety management experts in the apparel industry. Subsequently, a questionnaire survey conducted among seventy health and safety management professionals. The data collected were analyzed using content and statistical data analysis to develop a leadership assessment tool. Research findings revealed that the score rating assessment method will ensure quality and transparency in the work done by leaders which in turn will result in good health and safety performance. The research recommends the use of score rating to assess the commitment of leadership to health and safety management in the apparel manufacturing sector in Sri Lanka.

Keywords
Leadership Assessment Tool, Apparel Industry, Health And Safety Management, Sri Lanka

1. Introduction

Management and leadership have to be integrated to deliver proper health and safety services in a workplace and it may involve different types of outlooks, skills, and behaviours (Gary, 2003). The total cost of workplace accidents and ill health accounts to approximately 4% of the world’s gross domestic product, and cultural aspects are found to cause most of the issues that arise in health and safety management (Fernando, 1997). Each processing stage of a production facility from the production of materials to the building, finishing, colouring and packaging of the final product poses risks for workers (Vanderzee, 2007). Moreover, according to Zubar (2014), if leaders can show their workers that they are serious about health and safety, the workers are more likely to follow the leaders (Australian Government Statutory Agency [AGSA], 2011). According to Dheerasinghe (2008), effective occupational health management practices, awareness programs and a good safety culture among the workforce can prevent many deaths and diseases. The author has further highlighted issues such as lack of safety systems, management commitment, employee involvement, effective assessments and organizational responsibility as causing these deaths and diseases. Shortcomings in the occupational safety and health coverage of workers has become a key concern as only about 30% of the labour force is presently covered by the main statutory provisions on occupational safety and health (International Labour Organisation [ILO], 2017).

Green concepts are vital to the apparel manufacturing industry to ensure its sustainability, proper health and safety practices by its workers, mitigation of greenhouse gas emissions and biodiversity (Central Institute for Labour Protection [CILP], 2008). About 4,000 accidents occur annually in the apparel industry in Sri Lanka (ILO, 2017). Effective risk management in the apparel sector highly depends on the commitment to health and safety displayed by those who operate and manage the business (Dheerasinghe, 2008). Occupational safety and health in the apparel manufacturing sector will safeguard its most valuable and indispensable human asset (Kelegama and Frikz, 1999). Because of lack of health and safety assessments, there are many occupational, environmental and organizational issues in the apparel sector. Industry assessments are mostly to fulfill internal and external health and safety audit requirements. Only a proper leadership assessment system will be able to identify these issues. Hence, health and safety management assessment using a suitable leadership assessment tool has become necessary for proper health and safety management in the apparel industry in the country. This study therefore focussed on identifying a leadership assessment tool suitable for health and safety management in the apparel manufacturing industry in Sri Lanka.

2. Literature Review

2.1 Health and Safety Practices in the Apparel Sector

According to the Central Bank of Sri Lanka Annual Report (2013), and the Department of Census and Statistics of Sri Lanka (2014), 58% of the total industrial export earnings and 52% of the industrial sector labour force in the country come from the textile and apparel industry. Hence apparel manufacturers in Sri Lanka are certainly interested in minimising environmental and occupational safety issues that arise as a result of the apparel manufacturing processes (Wijendra, 2013). According to Embuldeniya (2015), health and safety indicators include communication or awareness of health and safety practices measured in terms of employee satisfaction expressed through messages they communicate on health and safety. The author has further stated that designing safety equipment, protective devices and clothing, maintaining records and statistics to identify problem areas and unsatisfactory trends and carrying out regular risk assessment audits, inspections and checks and taking action to eliminate the identified risks as some of the safety practices found in the apparel industry. Nawan and Shafi (2011) have stated that working conditions, layout and location, ventilation, space for movement, temperature, lighting, arrangement of tools and equipment affect employee productivity. They have further found training programs that educate employees on proper safety procedures, continuous programs on working habits and methods that will avoid accidents, employer commitment and identifying and implementing comprehensive changes in a consultative manner as practices currently followed in the apparel industry in relation to health and safety.

2.2 Leadership and Management Commitment towards Health and Safety

Leadership and management commitment to health and safety is recognized as a fundamental component of an organization’s occupational health and safety agenda (Integrated Management System [IMS], 2017). Clear lines of authority, understanding of safety statements, trust and engagement, safety information and communication all of which play a crucial role in any organization are the key enablers of leadership assessment (Degreef, 2004). Consultative style, role models, safety accountability, and safety feedback also enable health and safety assessments (Champoux, 2001). Furthermore, proper safety performance and high productivity are linked to consultative management style that can develop a positive safety culture (Bjurstrom, 2009). A safety program alone cannot be successful unless the responsibility of accomplishing safety activities is transferred from the top management to the lower levels of authority

(Kirsten, 2010). According to Goetzel (2008), policy and strategy, people, partnerships and resources and processes are the key enablers of health and safety leadership development. The elements of leadership and management commitment towards health and safety are given below (Bass, 1994; Firth-Cozens, 2001; Yukl, 2002; Zohar, 2003; Hofmann, 2004 and Flin, 2013):

- Policy
- Organizing
- Planning
- Measuring performance
- Auditing and reviewing performance
- Co-operation
- Training on health and safety

These elements have been developed over a period of time and customized according to the context.

2.3 Leadership Assessment Tools Available in the Industry

A sound business enterprise must check its safety practices as carefully as it checks its accounting records (Chair, 1999). According to Wang (1995), debts taken in situations, where there are losses or injuries should balance the credits that accrue from the adequacy of the safeguards adopted to prevent those losses and injuries. Health and safety audits are not just inspections but are evaluations of all aspects of a program with particular emphasis placed on the quality as well as the quantity of safety and health activities of every level (Gupta, 2010). Chair (1999) stated that the fundamental goal of a health and safety audit is to verify that health and safety activities comply with institutional policies and federal, state and local regulations and to inspect those practices. Health and safety assessment is defined as a monitoring function of an organization performed to locate and report existing and potential hazards that could cause accidents in the workplace (Howard, 2002). Document analysis, workplace observations and interviews are considered as safety culture assessment tools (Henry, 2005). Leadership assessment inventories (William, 2011) and leadership assessment questionnaires (Henry and Ramsey, 1999) are considered as the evaluation criteria of safety leadership.

3. Research Methodology

Mixed method has less flaws and problems than any of the mono methods (Tashakkori and Teddlie 1998). It enriches the validity and reliability of the results of a study and the comprehension of the studied phenomenon, while enabling new dimensions to emerge (Teddlie and Tashakkori 2003). This research therefore used the mixed method. It began with a comprehensive literature synthesis. Data collection for the study was conducted in two phases, a preliminary survey with semi structured interviews followed by a questionnaire survey. The preliminary survey was carried out among ten health and safety management personnel working in apparel manufacturing factories. All of the participants, three senior safety executives, five safety officers and two safety and risk management executives, were entrepreneurs each with more than 10 years of experience in health and safety management. To refine the literature findings, the data collected were analysed using content analysis. The questionnaire that was subsequently developed was distributed among 100 health and safety officers, executives, and departmental heads of several organisations operating in Sri Lanka. Seventy out of the 100 questionnaires distributed could be collected giving a response rate of 70% for the questionnaire survey. Thirty from large scale organisations and 20 each from medium scale and small scale organizations participated in the questionnaire survey. All of the respondents had more than 5 years of work experience. Table 1 presents the profiles of the respondents.

Table 1: Profile of the respondents of the preliminary survey

Type of organization (Apparel)	Designation	Total number of participants
Large scale	Safety Manager	5
	Senior Safety Executive	4
	Health and Safety Compliance Executive	6
	Safety Officer	15
Medium scale	Health and Safety Director	3
	Safety Compliance Senior Executive	7
	Environmental, Health and Safety Officer	10
Small scale	Safety and Compliance Executive	12
	Executive- Safety and Risk Management	8

Quantitative analysis was carried out using relative importance index (RII), which was calculated as given below.

$$\boldsymbol{RII = \frac{\sum w}{A * N}}$$

RII= Relative Importance Index; w= Weighting given to each factor by the respondents, A= Highest weight and N= Total number of respondents.

Participants were requested to indicate their responses on a five point Likert scale so that their responses could be analysed using statistical tools.

4. Research Findings

The research was done in two stages. Firstly, significant health and safety systems used in the apparel industry were identified. Secondly, leadership assessment tools were integrated with health and safety management systems that were identified from the questionnaire survey.

4.1 Identification of Health and Safety Systems used in the Apparel Industry

Many health and safety systems could be identified from the literature synthesis and they were subsequently refined during the preliminary survey. Thereafter health and safety systems currently being used in the apparel industry were ranked and prioritised based on their RIIs calculated using the rankings given to them by the respondents of the questionnaire survey. The results of the questionnaire survey clearly indicated that “safety planning” with a RII of 0.365 is the system, most applicable in the apparel industry in Sri Lanka. “Measuring performance” and “employee assessments’ are ranked second and third with a RII of 0.355 and 0.351 respectively. These top ranked practices are being used often in the industry. Table 2 presents the rankings of the seven health and safety systems identified.

Table 2: Significant health and safety systems used in the apparel industry

No	Health and safety systems used in the apparel industry	Level of practicing (%)					RII	Ranking
		SD	D	N	A	SA		
		1	2	3	4	5		
1	Safety planning	0.00%	0.00%	0.00%	17.50%	22.50%	0.365	1
2	Measuring performance	0.00%	0.00%	2.50%	17.50%	20.00%	0.355	2
3	Employee assessments	0.00%	0.00%	2.50%	17.50%	20.00%	0.351	3
4	Procedures	0.00%	0.00%	2.50%	20.00%	17.50%	0.350	4
5	Training on health and safety	0.00%	0.00%	5.00%	17.50%	17.50%	0.345	5
6	Auditing and reviewing performance	0.00%	0.00%	2.50%	27.50%	10.00%	0.335	6
7	Inspections	0.00%	0.00%	7.50%	17.50%	15.00%	0.331	7
1-Strongly disagree, 2-Disagree, 3-Neutral, 4-Agree, 5-Strongly agree								

4.2 Applicability of leadership assessment tools to health and safety management systems

The leadership assessment tools that were identified from the literature were refined using the preliminary survey and Table 3 below presents nine of those tools that are being practiced in the apparel sector in Sri Lanka. These leadership assessment tools identified were integrated with health and safety management systems that were identified from the questionnaire survey. The three topmost health and safety management systems that can be used with each leadership tool ranked based on their RIIs are presented in Table 3.

Table 3: Integrating leadership assessment tools with health and safety management systems

No	Leadership assessment tools	Health and safety management systems	Level of practicing (%)					RII	Ranking
			SD	D	N	A	SA		
			1	2	3	4	5		
1	Document analysis	Safety planning	0.00	0.00	24.00	31.00	45.00	0.850	1
		Measuring performance	0.00	0.00	25.00	29.00	43.00	0.840	2
		Employee assessments	0.00	0.00	25.00	32.50	42.50	0.835	3
2	Workplace observation	Procedures	0.00	25.00	35.00	35.00	30.00	0.890	1
		Employee assessments	0.00	0.00	22.50	35.00	42.50	0.840	2
		Safety planning	0.00	0.00	30.00	27.50	42.50	0.835	3
3	Interviews	Procedures	0.00	0.00	35.00	40.0	50.00	1.030	1
		Auditing and reviewing performance	0.00	25.00	35.00	35.00	30.00	0.890	2
		Safety planning	0.00	0.00	25.00	35.00	40.00	0.830	3
4	Leadership assessment questionnaire	Safety planning	0.00	0.00	25.00	37.50	38.50	0.865	1
		Employee assessments	0.00	0.00	25.00	37.50	37.50	0.825	2
		Procedures	0.00	0.00	30.00	40.00	30.00	0.800	3

No	Leadership assessment tools	Health and safety management systems	Level of practicing (%)					RII	Ranking
			SD	D	N	A	SA		
			1	2	3	4	5		
5	Leadership checklists	Inspections	0.00	0.00	25.00	32.50	42.50	0.835	1
		Auditing and reviewing performance	0.00	0.00	25.00	32.50	41.50	0.830	2
		Procedures	0.00	0.00	25.00	40.00	40.00	0.820	3
6	Leadership audits	Inspections	0.00	0.00	25.00	32.50	42.50	0.845	1
		Auditing and reviewing performance	0.00	0.00	25.00	32.50	40.50	0.830	2
		Procedures	0.00	0.00	30.00	35.00	35.00	0.828	3
7	Competency assessments	Employee assessments	0.00	0.00	10.00	40.00	50.00	0.880	1
		Measuring performance	0.00	0.00	22.50	30.00	47.50	0.850	2
		Safety planning	0.00	0.00	22.50	40.00	37.50	0.830	3
8	Leadership inventory	Training on health and safety	0.00	0.00	25.00	40.00	35.00	0.820	1
		Safety planning	0.00	2.50	22.50	40.00	35.00	0.815	2
		Procedures	0.00	10.00	15.00	37.50	37.50	0.805	3
9	Score rating system	Safety planning	0.00	0.00	40.00	27.50	47.50	0.935	1
		Employee assessments	0.00	0.00	5.00	40.00	55.00	0.900	2
		Measuring performance	0.00	0.00	17.50	32.50	50.00	0.865	3
1-Strongly disagree (SD) 2-Disagree (D) 3-Neutral (N) 4-Agree (A) 5-Strongly agree (SA)									

According to the questionnaire survey results, “safety planning”, “measuring performance” and “employee assessments” with a RII of 0.850, 0.840, and 0.835 respectively are the safety management systems that can be used in the document analysis of leadership assessments. “Score rating system” has the highest RII. The RIIs of “safety planning”, “employee assessments” and “measuring performance” are 0.935, 0.900 and 0.865 respectively. These safety assessment tools will help companies to determine important aspects of the safety measures they have been adopted and will promote employee involvement in health and safety issues. RIIs of all health and safety management systems coming under each leadership tool are either 0.8000 or more. Therefore, it is clear that the leadership tools identified will strongly contribute to all of the health and safety systems used in the apparel sector.

5. Conclusions and Recommendations

The need for a leadership assessment tool in the apparel manufacturing industry in Sri Lanka was identified by analysing safety practices adopted by the industry. The majority of the health and safety management systems identified can be applied in a flexible working environment with a proper leadership assessment method. According to the findings, the score rating tool can be adopted as a leadership assessment tool in the apparel manufacturing industry so that benefits such as improved safety management and leadership performance can be gained. Cost saving and flexibility of management are the benefits of the score rating tool system. Because of time constraints, the scope of the research had to be limited to identifying only the required level of assessment in small, medium and large organisations of the apparel industry.

Based on the results, it can be recommended that a leadership assessment tool should be developed to measure the leadership commitment to health and safety management in the apparel manufacturing industry in Sri Lanka. This research was focused only on the local apparel manufacturing industry and thus further studies on this subject are necessary to educate and convince the leaders in Sri Lanka who are involved in managing health and safety at workplaces of different industries on the benefits of the system using presentations, seminars, workshops and continuous professional development (CPD) programs. The other employees can be subsequently educated on the results of the performance development in health and safety management, which will most probably be the preference in the future. It will be better to consider external customer requirements when developing an assessment tool to enhance the quality of leadership given to health and safety management. This tool is recommended for use with all the safety practices followed at workplaces and for fulfilling the internal and external audit requirements for improving the transparency of the management. The leadership assessment tool with to health and safety management.

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Review on Photocatalysis Applications in Construction

Muhammad Yasir Sadiq
(Graduate student, East Carolina University, Greenville, NC, USA)

Amin K. Akhnoukh
(Associate Professor, East Carolina University, Greenville, North Carolina, USA)
akhnoukha17@ecu.edu

Abstract
Many construction projects are composed of concrete or mortar. After construction of such projects, the material faces challenges which cause aesthetic as well as physical deterioration. This paper discusses the application of Heterogeneous Photocatalysis which is a versatile, cost efficient and environmentally friendly treatment technology. The natural resources that are being used for demonstrating the self-cleaning characteristics of the photocatalytic materials is laudable. The most popularly used photocatalytic material is Titanium dioxide (TiO2).Multiple reasons are discussed for TiO_2 being beneficial for the construction industry. The principal utilization of TiO_2 as a photocatalytic building material is due to its self-cleaning, self-disinfecting and sustainability properties. The basic mechanism of photocatalysis is also analyzed for actual understanding of the project. The photocatalytic application for a greener road environment is worth mentioning. The paper discusses that which type of TiO_2 coating is the most sustainable and best choice for an urban road environment which will efficiently eliminate the harmful nitrogen oxides (NO_X) and volatile organic compounds (VOCs). The effect of particle size on the cost and productivity of the photocatalytic material is mentioned. The variability of the coating mix with the reduction of NO_x and VOCs.

Keyword
Heterogeneous Photocatalysis, Titanium Dioxide, Pollution , Environemnt,self-cleaning concrete

1. Introduction

The research on photocatalytic capability of a material and its applications has started to gain momentum from different aspects. The characteristics and the applications of the materials are undoubtedly a prudent choice for today's world where pollution is added in a proliferated amount because of vehicle and industry emissions. The photochemistry of TiO_2 has become a critical research subject for the future. Different research projects in the world are striving hard for a better, sustainable and green environment for our future generations. This subject gained momentum in research when the photocatalytic splitting of water on TiO_2 and Sr-doped TiO_2 respectively became successful in the 1970's. Two important effects related to nature of photoactive TiO_2 coatings had by this time been discovered a)- self-cleaning effect due to redox reactions promoted by sunlight (or in general weak U.V. light) on the photocatalytic surface and b)- the photo-induced super hydrophilicity of the catalyst surface, which enhances the self-cleaning effect(inorganics causing dirt and stains on surfaces can be easily removed due to rainwater soaking between the adsorbed substance and the TiO_2 surface). For the photocatalysis to initiate U.V. light is fundamental which means that this process will be more productive in the day time than in any other time. The solar energy reaching the earth's surface is about 5 x 10^{24} J per year. This is more than the 10^4 times the annual worldwide consumption of energy. This is the best part that we are using natural resources for this process. This enormous source of energy is utilized with exceptionally engineered construction materials which have the potential to make the environment cleaner and free of pollutants.

1.1 Photocatalysis

Photocatalysis is the photoreaction in the presence of a catalyst. The term "photocatalysis" is in widespread use and is here to stay; it is not meant to, nor should it ever be used to, imply catalysis by light, but rather the "acceleration of a photoreaction by the presence of a catalyst". The term "photoreaction" is sometimes elaborated on as a "photoinduced" or "photoactivated" reaction, all to the same effect (Mills and Hunte, 1997). The process of photocatalysis is very prominent in the presence of light as the photocatalytic efficiency of the building materials is visible. The study of photocatalytic reactions was initiated in 1970's. During the photocatalytic process light is consumed by one or two reacting species and this is the reason that catalyst is added which does not get consumed and accelerates the reaction.

1.2 Types of Photocatalysis

Photocatalysis is the acceleration of a photoreaction in the presence of light. There are two types of photocatalysis which are homogeneous and heterogeneous Homogeneous Photocatalysis the reactants and photocatalyst exist in the same phase

In Heterogenous Photocatalysis, the reactants and the photocatalyst exist in a different phase from the reactants. The hetero generous photocatalysis will be discussed in more detail later

1.3 Heterogeneous Photocatalysis :-

Heterogeneous photocatalysis is based on the irradiation of a semiconductor photocatalyst in contact with a liquid or a gaseous environment. TiO2, ZnO, and CdS are widely used examples (Cassar,2004).

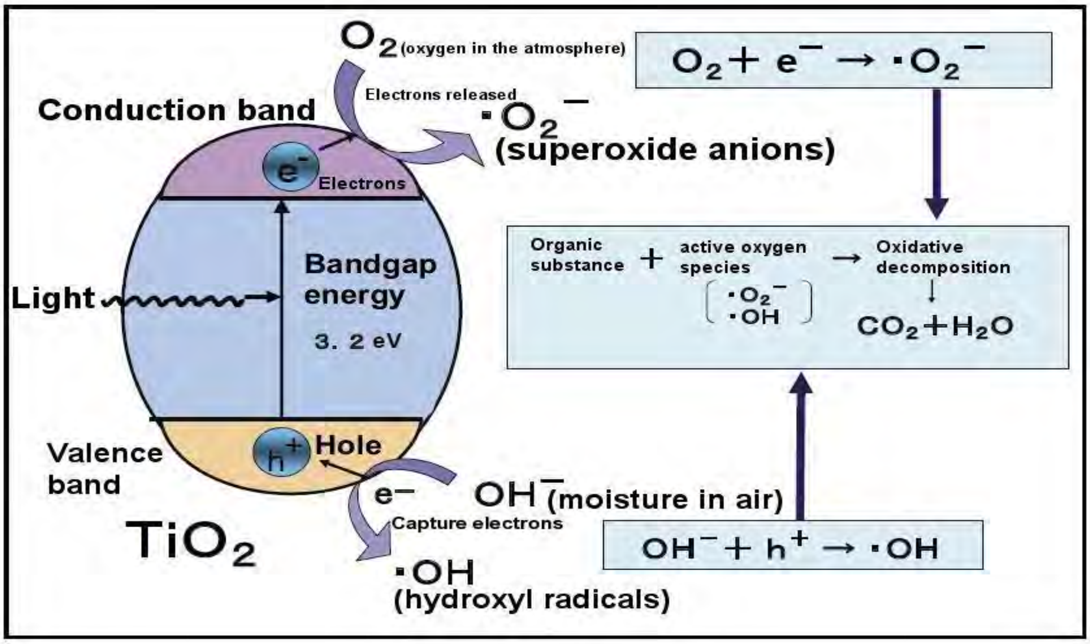

Figure 1 Mechanism of Photocatalysis with TiO_2 (Chen,1970)

A band gap exists between the valence band and conduction band. The electron gets promoted form a valence band to the conduction band in the presence of Ultra violet radiation or fluorescent light. During promotion of electron from a valence band to conduction band a hole is left on the valence band. The holes oxidize the donor molecules. The energy of band gap is 3.2 ev.

$D + h^{+} \rightarrow D^{\bullet +}$

Whereas the conduction band electrons can reduce appropriate electron acceptor molecules.

$A + e^{-} \rightarrow A^{\bullet -}$

The afore-mentioned explanation presents a brief description to the chemistry of the photochemical reaction in which TiO_2 is seen as the photocatalyst.

2. TiO_2 as a Photocatalyst

TiO_2 is used as a photocatalyst. Although, there are several other metal oxides of vanadium, chromium, zinc, tin and cerium. TiO_2 has ample amount of applications such as it is most widely used inorganic pigment for varnishes and plastics. It is used as a white pigment in paints because of its strong resistance to discoloration under UV light. It is also used in foods, pharmaceuticals and cosmetics. The reason of using TiO_2 is that it is very cost efficient and has the capability to go under quick reactions at ambient operating conditions (room temperature, atmospheric pressure). TiO_2 is also used as a photocatalyst because of being chemically stable and compatible with traditional construction materials such as cement. TiO_2 is very effective under weak solar irradiation in various conditions of the environment.

The reasons for using TiO_2 as a photocatalyst are that in addition to the self cleaning characteristics that it shows in the presence of light. It also introduces to its various other characteristics which are the anti-fogging effect, water treatment, air cleaning effect and anti-bacterial effect. Due to these reasons TiO_{2is} considered as a very beneficial oxide in the industry. TiO_2 ceramic tiles are considered to be very effective against organic and inorganic materials and also towards bacteria. Hence when such applications of TiO_2 are seen then there comes no question in using any other metal oxide for photocatalytic process.

2.1 Forms of TiO_2

TiO_2 occurs naturally as rutile, brookite and anatase. Now the question comes that which one is the best for photocatalysis. Compared with rutile and brookite, anatase shows the highest photoactivity (Benedix *et al.*,2000).

Despite the intensive study of TiO_2 there is no generally accepted explanation for the differences of photocatalytic activity of different polymorphs or surface orientations. The general perception that anatase has a higher photocatalytic activity compared to rutile TiO_2 is confirmed by out measurements on extended planar epitaxial thin films . Anatase exhibits an indirect band gap that is smaller than its direct band gap. For rutile, on the other hand, its fundamental band gap is either direct or its indirect band gap is

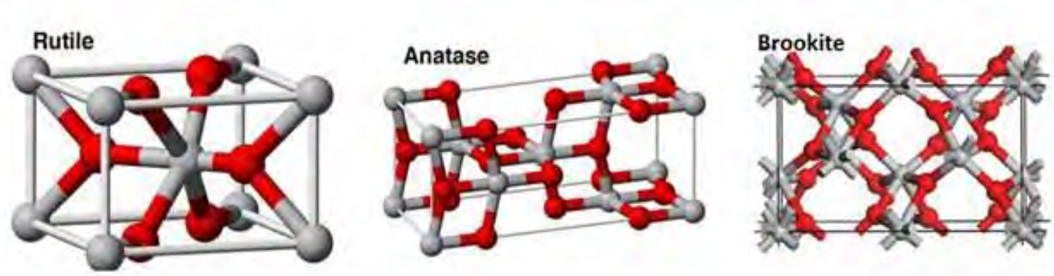

Figure 2 Forms of TiO2 (Naturally Occuring) (Austin and Lim,2008 ; Woodley and Catlow,2009)

very similar to its direct band gap (Luttrell *et al.,* 2014). Anatase, the most commonly used photocatalyst in concrete, is capable, under natural sunlight, of degrading certain atmospheric pollutants, e.g. NO_x, Volatile organic compounds (VOCs) and non-volatile organic residues due to charge transfer (redox) processes on the catalyst surface (Macphee and Folli 2016). The previous researches suggest that anatase has more photocatalytic activity any other of its forms due to which it is used majorly in the environment.

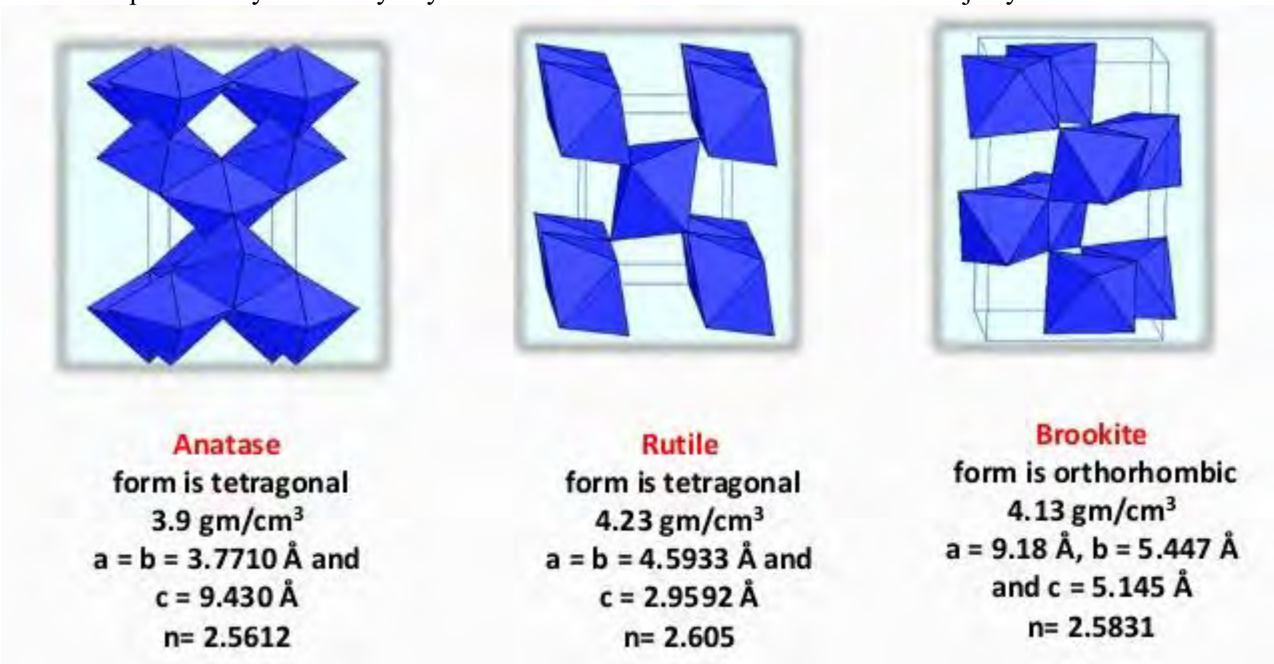

Figure 3 Types of TiO2 (Naturally occurring) and their properties (Al-obaidi, 2012)

2.2 Nano and micro size particles

In relation to size TiO_2 can exist either in micro or nano size. The work done by various researchers suggest that the size has a solid effect on the photocatalytic efficiency of the material. At first nano particles were considered as a favorite choice for better results but latest research opposes this approach. Although TiO_2 is chemically inert, TiO_2 nanoparticles can cause negative health effects, such as respiratory tract cancer in rats (Trouiller B 2009) investigate TiO_2 nano particles- induced genotoxicity, oxidative DNA damage, and inflammation in a mice model. The increased use of nano materials in commercial products has raised a growing public debate on whether the environmental and social costs of nanotechnologies outweigh their numerous benefits (Colvin VL 2003). Up to now, few studies have investigated the toxicological and environment effects of direct and indirect exposure to nano materials and nano particles and no clear guidelines exist to quantify these effects (Hye Won K 2009). This research opens doors for the usage of micro sized TiO_2 powders instead of nanometric ones. They are cost efficient as well as safer for both the environment and the workers on the site which practically apply these materials as a coating on the materials such as concrete blocks or the different parts of the road for a better healthy environment which is more cleaner and free of bacteria. Traditionally it was thought that a decrease in particle size such as nano particle will perform better than micro particle. However the latest research suggests something else as health effects of nano particles cannot be compromised.

3- Applications of TiO_2

TiO_2 due to having various beneficial and prominent characteristics has various practical applications in the construction industry.

3.1 Residential and Commercial Construction

It is a common phenomenon that the aesthetic and luster of the surface of ordinary buildings are gradually lost with time. The building surface could be soiled by greasy and sticky deposits, which results in a strong adherence of ambient dusts. As a result, dirt built up on the surface reduces the visual appearance (Jun Chen 2009). The self-cleaning product having a coating of TiO_2 can save so much money for maintenance of such a dusty building and can be very cost effective. Hence the use of TiO_2 Besides self-cleaning cementitious materials, TiO2-based selfcleaning exterior building products including tiles and glass have been widely commercialized and applied. About 270 patents have been registered in the photocatalytic technology domain by TOTO Ltd (TOTO Ltd 2008). Another important commercial product among the photocatalytic building materials is TiO2 based self-cleaning glass. Its successful application is not only due to the self-cleaning function but also strengthened by the light-induced anti-fogging property. Fogging of the surfaces of mirrors or glass happens when steam is cooled down on the surface to form fine water droplets. As droplets fall or form on a hydrophilic surface, they rapidly coalesce to form a water sheet. The visible view behind the glass can still be observed without blockage or distortion. Moreover, the superhydrophilic layer makes the glass dry without leaving the traditional droplet marks (Sanderson K 2001). Similarly with these advancements, many other researches have been proposed which indicate a new method of cooling buildings by sprinkling water on the surface of buildings which are coated with TiO_2. This new application of photocatalytic building materials can result in significant reduction of electricity consumed for air conditioning (Hashimoto K 2005).

3.2 In an urban road environment

The UK is currently facing a fine of \$500 million for London exceeding the PM10 particle pollution limits more than 35 times for the entire year (Olek J *et al*, 2003). This study proves the necessity of photocatalytic coating on a huge scale. Some benefits of photocatalytic concrete are that it decomposes chemicals that contribute to soiling and air pollution, keeps the concrete cleaner, and reflects much of the

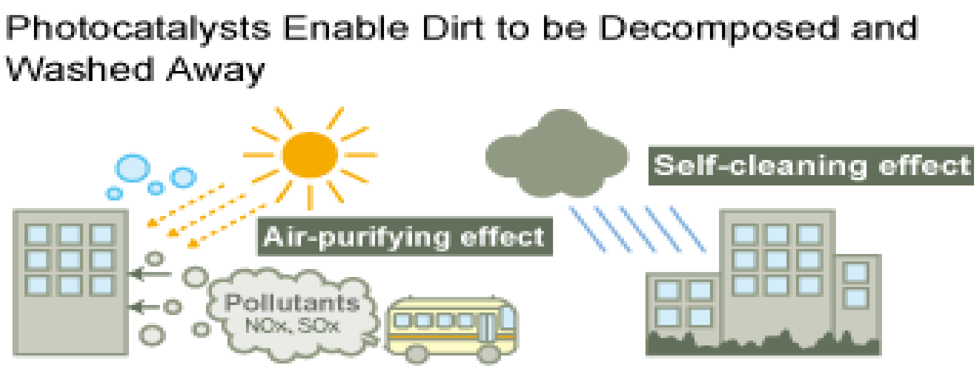

Figure 4 Effects of photocatalysis ("Trends in Japan | Web Japan")

sun's heat and reduces heat gain because of its white color (Chusid M., 2006). However, a lot of work has been done to promote carpooling and better public transportation has been designed but still the vehicle emissions continue to grow in the environment due to which the importance of photocatalytic concrete cannot be neglected. It is to be noted that the contact of TiO_2 with sunlight is very important. Once they stay in contact then the photocatalytic effect becomes very prominent instead of having the TiO_2 mixture within the concrete layer. If the TiO_2 coating is brushed on the top of the surface pavement then they seemed to be more durable in case of light pedestrian traffic whereas in case of high abrasion of vehicles the top coating of the TiO_2 seems to get abraded.

Table 1 Material Cost for each Coating Type (Shen *et al.* 2012)

Coating type	Material cost		Observed pollutant reduction			
	Total material cost ($\$/\mathrm{ft}^2$)	Total material cost ($\$/\mathrm{m}^2$)	Static chamber (120 min)		Converted Static chamber (29.83 min) total% NO reduction	Decrease in infiltration rate (%)
			Total% toluene reduction	Total% TMB reduction		
Commercial water-Based TiO_2 (CWB)	0.9955	10.70	61.86 ± 14.06	94.64 ± 1.85	97.59	20.60
Cement–water slurry (CWSH)	0.1860	2.00	13.23 ± 1.62	81.65 ± 1.50	85.04	58.29
Driveway protector mix (DPM)	0.3876	4.17	61.65 ± 10.77	93.87 ± 1.09	97.92	30.49
Pureti (PUR)	0.1000	1.08	43.42 ± 1.79	89.50 ± 4.05	95.79	11.92
Cement–water slurry low (CWSL)	0.1655	1.78	78.82 ± 9.22	97.26 ± 0.63	96.94	51.50
Cement/aggregate mix (CAM)	0.3045	3.27	21.62 ± 4.30	68.28 ± 5.99	55.35	3.85
Cement/aggregate mix high (CAMH)	0.3030	3.26	–	–	81.03	3.49

Table 1 shows different coating types which have been mixed together with different concentrations of cement and other substances depending on the coating type. After the study of these different coating types Driveway protector mix was considered the best choice as it is a mixture which consists of a transparent liquid drive way protector (siliconate, water-based concrete sealer) and TiO_2 uniformly mixed together and brushed on to the surface of pervious concrete (Shen *et al.*, 2012). The conclusions of this table suggest that DPM is the best mixture as compared to cost efficiency and performance of its photocatalytic capability. The highest reduction in pollutants and the highest resistance to weathering can be seen with this mixture which is a breakthrough for the photocatalytic research. The white color of the TiO_2 particles seen in the DPM coating could potentially be used as pavement marking materials, at the same time achieving air purification effect (Shen *et al.*, 2012). The other coatings seem not to produce the desired result because of having more concentration of other components in the mixture such as cement than TiO_2. However, more research is required as this is still a nascent research category which still demands substantial amount of concentration to benefit the future generations to come.

4-Conclusions

This paper displays the modern research and development in the construction industry specifically concerning photocatalytic building materials and their carious applications. The scientific, laboratory and on site research avers that photocatalytic building materials are the sustainable future of a smart developing construction industry. Several photocatalytic materials have been used in various projects and the results affirm that photocatalytic materials cannot only retain the aesthetics of the building over time but it can also support well enough in making the environment free of micro-organisms. The paper also exhibits information regarding the approach to applying the photocatalytic materials such as it is discussed it detail in the case of roads which asks to keep the concentration of the mixing material in check with the TiO_2 whereas it also suggests to apply the mixture on the top of the pavement instead of mixing it inside because that would inhibit the direct reaction of TiO_2 with sunlight. Although the efficiency and durability of these materials still needs further investigation in all kinds of weathers and environment but the prospective usage of these photocatalytic building materials display massive and auspicious potential.

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Application of Value Engineering Concept to MEP Works in Sri Lankan Construction Industry: A Case Study

Bandara D.G.B.S., Sandanayake Y.G.
University of Moratuwa, Moratuwa, Western Province, Sri Lanka
buddhinissbandara@gmail.com, ysandanayake@uom.lk

Ekanayake B.J.
University of Moratuwa, Moratuwa, Western Province, Sri Lanka
ra-biyanka@uom.lk

Abstract

Mechanical, electrical and plumbing (MEP) systems are the life-blood of a building, which enhance functionality. However, the value of MEP works constitutes a large portion of construction cost. Due to increasing complex MEP systems and high cost, clients demand value for their money, while enhancing functionality. Value engineering (VE) is renowned as an approach for improving quality and functionality, while ensuring value for money. Therefore, this research investigates the application of VE to MEP works in Sri Lankan construction industry. A qualitative approach was adopted and three building projects, which have employed VE were selected for data collection through unstructured interviews, document review and observations. Subsequently, data were analysed using content analysis. The study revealed that the application of VE to MEP works has potential saving opportunities such as improvements in capacities, locations and material in MEP works. The challenges encountered include difficulty in identifying the possible scope for VE, poor attitude of people and lack of information. Most of the difficulties can be overcome if a formal value study process and a team with a trained facilitator is employed. The study recommends the use of VE to be more systematic and the awareness of the concept should be improved.

Keywords

Value Engineering; Mechanical, Electrical and Plumbing Works; Sri Lankan Construction Industry

1. Introduction

Construction is a large, multifaceted and dynamic industry with processes for building new structures and engineering projects (Çelik *et al.,* 2017). In construction projects, primary needs and functions for the activities in the constructed product are provided by the mechanical, electrical and plumbing (MEP) systems (Chen *et al.,* 2012). Kuo *et al*. (2011) indicated that MEP systems typically include air-conditioning, water supply, gas pipes, sanitary lines, telecommunication systems and security networks. Moreover, MEP systems are positioned in limited space, restricted by the design, construction and maintenance criteria provided for them (Clemente & Cachadinha, 2013). As per Khanzode (2010), the complexity of these systems has increased over the years with the rise in material costs and decline in skilled labour component required for MEP installation, even though owners are demanding projects to be completed faster at lesser cost. Khanzode *et al.* (2008) identified that cost of MEP and fire protection systems can escalate up to 50% of total project cost and it was also proved by Bosché *et al.* (2014) stating that a significant amount of construction cost is constituted by MEP works. Therefore, an extensive role of the construction sector is played by MEP works, in terms of cost and function and thereby for the value enhancement. Since quick delivery of projects is anticipated by the proprietors at a lesser cost, better strategies are constantly sought by the project teams to address these difficulties (Khanzode, 2010). In light of this, Ciocan and Onutu (2017) pointed out that the development of competitive construction firms towards a meaningful, durable and economic environment is enabled by value engineering (VE). Amongst various definitions for VE, Shu *et al.* (2010) defined VE as ‘‘the systematic application of recognized techniques which identify the function of a product or service, establish a monetary value for that function, and provide the necessary function reliability at the lowest overall cost”. Kalani *et al.* (2017) concluded that researchers have probed in to VE and its application in engineering subcategories. Regardless of the heightened application of VE in the construction industry, Zhang *et a.,* (2009) argued that the construction industry is practising VE in the same fashion as it was 50 years ago. Karunasena and Gamage (2017) substantiated this claim by explaining that VE concept and its applications are not well embraced by the construction sector of majority of developing countries. According to Nguyen and Luu (2016), 5–10% cost savings from construction projects are achieved through VE studies. Given the fact that a substantial portion of construction cost is compounded by MEP works, application of VE to MEP works would influence the value of a construction project to a great extent. This research therefore aims to investigate the application of VE concept to MEP works in building construction projects in Sri Lanka.

2. Literature Review

2.1 Significance of MEP works in construction projects

MEP systems perform core tasks in the architectural engineering by performing the most critical role in construction segment, of providing a comfortable, safe living environment (Guo *et al.,* 2013). According to Wong *et al.* (2016), MEP installations are proved to be vital to any construction project when considering the number of workers and companies involved, hence, takes an imperative part in the construction industry. Mechanical drawings, mechanical drafting and design services, and the knowledge of electrical and plumbing equipment are important to MEP systems (Baig *et al.,* 2015). MEP and related systems contribute to the construction costs in large portion (Palomera-arias, 2015) and vary with the facility type and its unique system requirements (Riley *et al*., 2005). MEP systems can contribute up to 50% of project value in technically challenging projects like those focused on high technology, healthcare and biotech industries (Khanzode *et al.,* 2008; Clemente and Cachadinha, 2013). In fact, Khanzode (2010) identified the percentage from project cost for MEP work may vary from 40% to 60% in modern day high technology driven projects, playing an important role on project performance and success. Pérez-Lombard *et al.* (2008) highlighted the high contribution of energy consumption in buildings by MEP works and Palomera-arias (2015) pointed out the high operational and maintenance cost of the work due to MEP systems. Bosché *et al.* (2014) contended that compared to structural works, tracking MEP components is challenging. This is primarily as a result of increased complexity in configurations and less flexibility of installation compared to structural components. Modelling tools in the MEP works are rarely implemented by contractors due to the high costs and limited time (Guo *et al.,* 2013). Therefore, it is evident that with the increment of demand for upgraded living in contemporary buildings, the MEP systems of building projects have become more complex and challengeable (Chen *et al.,* 2012). If the time, cost and quality of construction works and services are properly managed, the success of construction works can be achieved (Haddadi *et al.,* 2016).

2.2 Application of value engineering to construction industry

Despite the availability of various techniques, the cost and time objectives are not fulfilled by many construction projects (Olawale & Sun, 2010). Hence, a new methodology named value engineering (VE) has been introduced to the construction industry to increase efficiency and client satisfaction as client requirements have become more onerous (Austin & Thomson, 1999). However, since its introduction, VE has been well employed in construction industry, as it enables realisation of life cycle cost and cost effectiveness of projects, although its effectiveness as a management technique does not seem to be fully understood by construction industry (Omigbodun, 2001; Naderpajouh & Afshar, 2008; Kemmochi & Koizumi, 2012). After VE entered the construction industry, approaches have been developed by the combined effort of academic research and practitioners in order to fit the unique characteristics of the industry (Khaled & Pandey, 2016). Apart from VE applications to structural components, the application of VE job plan to mechanical works is described by Patel *et al.* (2014) by explaining the use of as-built status of pipes, conduit and ductwork critical for control and earned value measurement. Although the potential of application of VE has already been demonstrated for the construction industry, lack of proper investigation into its applicability to reduce cost and enhance functionality of MEP systems s evident.

VE has been effectively implemented in many developed countries, and the concept has become more relevant to developing country like Sri Lanka with one reason being the absence of proper cost control techniques such as cost planning in Sri Lankan construction industry (Perera *et al.,* 2003). Moreover, application of VE in Sri Lankan construction industry lacks systematic approaches (Karunasena & Gamage, 2017). The Authors further revealed that life cycle cost of a project is not considered before application of VE techniques and Sri Lankan contractors are forced to mainly focus on reducing cost through VE while time and quality is given relatively less consideration. Although there are few examples on the application of VE to structural components, there is lack of a study on the application of VE to MEP works in Sri Lankan construction industry. Hence, the study aims to investigate the application of VE to MEP works in Sri Lankan construction industry.

3. Research Methodology

This research administered a qualitative approach, as qualitative methods contribute to conduct in-depth investigation (Fellows and Liu 2008; Yin, 2011). Due to lack of application of the VE concept in construction projects in Sri Lankan construction industry, drawing a large sample of respondents for the data collection was constrained. Since the case study approach enables in-depth examination (Yin 2009), it was considered that case study approach would supplement and extend the in-depth investigation for this research. Multiple case study design was selected in order to obtain better results through cross-case analysis. Yin (2011) explained that criteria for selecting a case depend on the convenience, judgement, time and cost constraints. In this research, three (03) building projects, which have applied VE concept to MEP works were selected considering all the aforementioned factors. The following selected cases were procured under design and build method:

- a university building,
- an office building, and
- a mixed development project.

Yin (2009) pointed out several data collection techniques to be included in case studies research such as interviews, observations and document reviewing. Punch (2005) highlighted interview method as one of the most commonly used data collection method when the research embodies a qualitative approach. Employing un-structured interview method is preferred in qualitative approach since the respondents are given the opportunity to answer independently with a limited control imposed by the researcher (Dawson, 2007). Accordingly, un-structured interviews were conducted for collecting data focusing on selected respondents, who involved in the VE study of the MEP works. Moreover, observations and document reviews were undertaken to capture data. The contract documents of the projects, VE proposals, drawings, specifications and standard documents related to MEP works were the documents reviewed during the study. The locations of each case were visited by the researcher and the current situation of the cases was observed in terms of quality and functionality. The key details about the projects and the respondents are summarised in Table 1.

Table 1: Profile of the Cases and Respondents

Details of the Case	Details of the Respondent
Project A	
• Project A is a university for 2,000 students, built, with a gross floor area of 65,000m^2 • Project cost is LKR 10.5 billion and cost of MEP works is LKR 2.8 billion • Total project duration is 30 months	• A1: Chief Engineer-MEP Designs with 21 years of work experience • A2 : Electrical Engineer-Designs with 8 years of work experience • A3: Mechanical and electrical engineer with 6 years of work experience
Project B	
• Project B is a demolition of existing building and to develop a new office building (MEP works), with a gross floor area of 8,900 m^2 • Project cost is LKR 425 million and cost of MEP works is LKR 141 million • Total project duration is 12 months	• B1: Chief Engineer-MEP Designs with 5 years of work experience • B2 : Electrical Engineer-Designs with 4 years of work experience • B3: Mechanical and electrical engineer with 5 years of work experience
Project C	
• Project C is a mixed development project with a gross floor area of 92,903 m^2 • Project cost is LKR 15.2 billion and cost of MEP works is LKR 5.07 billion • Total project duration is 39 months	• C1: Manager-MEP with 22 years of work experience • C2 : Electrical Engineer with 12 years of work experience • C3: Mechanical engineer with 8 years of work experience

For qualitative researches, content analysis provides subjective interpretation of texts through a systematic coding and pattern (Hsieh & Shannon 2005). The research findings were analised using manual content analysis.

4. Research Findings

4.1 Value engineering applications in the MEP works

In all three (03) cases, VE activities were initiated by the contractor by considering the requirements of clients to reduce the cost and enhance the value of the project. Cost reduction, high possibility of improvement and ability of choosing a variety of options were the major reasons for undertaking VE exercise for MEP works. According to A1, *"since the project is an educational institute and the society's attention is towards the project and reducing costs was a major concern"*. Possible usage of developing technologies related to MEP works was another driver. Respondents also claimed that VE was the best method to reduce the project cost without affecting the functional requirements or without compromising the quality. B2 explained; *"it was identified that the best way to reduce the cost without impacting the functional requirements was to do VE to MEP works"*. The total number of active members in Case A, Case B and Case C are five (05), six (06) and seven (07) respectively, and each team was consisting of a team leader, designers, cost estimators and other specialists. Team leaders of both Case A and Case B were the chief MEP Engineer. In Case C, the team leader was the project manager. In Case A and Case C, VE workshops were conducted in the construction stage and pre-construction stage respectively whereas, Case C has conducted two workshops in pre-construction and construction stages. The duration of workshops has lasted from one (01) to ten (10) days.

In Case A, after the appointment of VE team, they first have taken a comprehensive understanding about the project in order to identify high cost areas. The evaluation criteria adopted was based on initial cost, operational cost, maintenance cost, maintainability and reliability. In Case B, before VE workshop has begun, the team has got together and collected all the required information. They have recalculated all load calculations related to MEP works and identified the areas of improvement. In each identified area the major functions were analysed to identify primary and secondary functions. The evaluation criteria was based on initial cost, maintenance cost, maintainability, availability, efficiency and durability. The initial preparation of VE activities were similar in Case C also, however, the VE workshop activities seemed more organised and formal in Case C compared to other two cases. They have prepared reports for each VE proposal with cost comparison and, supporting documents such as relevant drawings and specifications. The evaluation criteria were based on life cycle cost, maintainability, availability, durability and aesthetics. Decisions taken at the VE workshops related to MEP works are summarised in Table 2.

Table 2: Decisions Taken at the VE Workshop related to MEP Works

Before VE Workshop	Decisions Taken at VE Workshop
Project A	
1. Dual stack water distribution system with one line for carrying drinking water the other for carrying treated water	1. To use a single stack water distribution system.
2. Each building was having 2 overhead tanks	2. To have one OH tank in the main building thereby removing all the booster pumps
3. Use uPVC as pipe material	3. Use various pipe materials according to the requirement
4. 3,500kVA electricity requirement from Ceylon Electricity Board and 1,800kVA backup power system	4. 3,000kVA CEB connection and full backup power system.
5. Central air conditioning (A/C) system with three high capacity chillers at one location	5. Three optimum capacity chillers at three locations and use of VRF systems accordingly
Project B	
1. A single direct line to deliver water to the overhead tank	1. Use of a break tank at the middle floor of the building and making pump sizes reduced
2. Use of PPR for pipe material according to the initial pressure requirement of the OH tank	2. Use of uPVC for pipe material due to the reduction of pressure requirement
3. Pumping stations in the sewer system	3. Use of gravity disposal system
4. Copper (CU) cables for electrical wiring	4. Aluminium (Al) cables for wiring
5. Split A/C system	5. Central A/C system
6. Staircase pressurisation duct inside mezzanary duct	6. Staircase pressurisation only with duct
7. Galvanized iron (GI) ducts to be used in air conditioning system	7. Pre-insulated ducts to be used in air conditioning system
Project C	
1. Ductile iron pipes in basement floor	1. Use of PVC pipes with catch pits instead of joints
2. Two metering systems for commercial tenants and apartments	2. Single metering system for both types
3. Separate earthening lines coming from each floor to the earth	3. Use of combined earthening cable from the seventh floor to ground floor
4. Cu tapes as down conductors	4. Mild Steel (MS) rods, Structural rebar
5. GI conduits	5. To use a combination of GI and PVC Conduits
6. Separate systems for fire horse and wet riser system	6. Using a combined system for both the systems
7. Ducted system for apartment kitchen hood	7. Separated kitchen hood extractor in each place
8. Single zone hotel water supply system	8. Three-zone system

Before VE Workshop	Decisions Taken at VE Workshop
9. $80m^3$ sewage holding tank	9. Direct disposal of sewage

In all three cases, VE study has not incurred much additional cost. However, the respondents highlighted about the unanticipated time consumption in the VE workshops. Despite the challenges, VE solutions have generated about 6%, 15% and 10-12% of cost saving from the total project costs of Cases A, B and C respectively.

4.2 Challenges in implementing value engineering to MEP Works

Implementing VE in MEP works was constrained due to many challenges as pointed out by the respondents. Most significant challenge was the difficulty in understanding the possible scope for VE. Difficulty in obtaining client's requirements was another significant challenge. A1 confirmed that "*even though we have identified some possible VE options at the pre-study phase where there were areas with high cost consumption, the client did not want the design to be changed from that aspect"*. Among the other challenges, difficulty in collecting all drawings and proper specifications was also highlighted. Difficulty in generating alternative ideas without compromising the quality was challengeable. B2 explained; *"sometimes they see that the original design is costly, but they cannot think about a way to reduce the cost without compromising the quality"*. Selecting the most impacting factor to be considered on evaluating alternatives was difficult. Moreover, if VE is proposed with cost increments it is very difficult to get approvals. Difficulty in keeping track of the implementation process was also pointed out. As explained by A2, *"after we complete the design, the project is not in our hands"*. Attitudes of the client and consultants are still not favouring VE concept restrains the creative execution of VE since they are not convinced of the true benefits of VE. Less awareness about VE and MEP works was a major challenge. C3 claimed; *"knowledgeable personals for both MEP works and VE are very rare in construction industry which is a huge barrier to the application of VE to MEP works"*. Lack of proper guideline and standard procedure for VE process in Sri Lanka is another barrier. Limited availability of resources also restrains the full potential of VE implementation. B1 explained; "*4-inch pipe and 6-inch pipe sizes are in Sri Lanka. But if the requirement is slightly more than 4 inches it cannot be gone with 4 inches but 6 inches is more than the requirement"*. Moreover, once the architect finishes the entire design, there is less opportunity for applying VE. Outdated standards in MEP works are challengeable. A3 pointed out; *"the standard values given in standards of various government authorities are outdated"*. The respondents have tried their best to overcome the aforementioned challenges to a great extent throughout the VE application process.

4.3 Strategies to optimise application of VE to MEP works

The strategies adopted by the respondents to overcome the challenges encountered are specific to the situation and can sometimes be generalised. Difficulty of understanding the possible scope was solved by informing the client and consultants frequently about the possible areas of VE. Since obtaining the exact requirement of the client is not possible, the team members sought client's approval when a possible application of VE is identified and by arranging meetings with the client. At the times when conducting meetings was not possible, verbal communication through telephone or electronic media were done. In order to get approvals, the proposals were incorporated with technical details and by arranging site visits and explaining using past project details. For the unavailability of the drawings, the teams had to contact consultant and request that information. When possible, alternative solutions cannot be made, the waste and non-value adding functions related to functions were removed to improve the designs. Preparing presentations in an understandable way to the client was the solution provided to overcome the lack of awareness about VE. Among the other strategies proposed, employing a VE facilitator to conduct a proper VE workshop was encouraged. Respondents were of the view that, this facilitator should be a person, who is aware of both MEP and VE concept. Changing the procurement process was suggested because implementation of VE during the concept design stage was well endorsed by the respondents. Hence it can facilitate the architect to formulate designs with the MEP design team. Beyond the project level, strategies such as creating formal education opportunities on VE and thus developing awareness and positive attitudes towards VE and updating outdated MEP related national standards was proposed. Moreover, the importance of introducing a standardised guideline for VE application in MEP works was also highlighted.

6. Conclusions and Recommendations

It can be inferred that the adoption of VE in the construction industry is still not developed to exploit the maximum benefits. Evidently, VE is applied in MEP projects in an ad-hoc manner and a formal process of VE workshop is not incorporated. Nevertheless, with the current level of applicability of VE to construction projects, major value improvements have been attained, primarily because all the MEP sections carry various opportunities for value improvement as identified through the case studies. Improving reliability of works is devised as the value achieving strategy used in all the MEP sections. The application of VE to MEP works has not only resulted in improving the value of construction by reducing cost and improving quality but also has reached to an optimum life cycle. VE teams encounter difficulties in adopting VE to MEP works majorly due to the absence of a proper VE team and a formal VE process in Sri Lankan context. But with the time and budgetary constraints and lack of assistance from regulatory bodies these situations are difficult to be overcome. Finally, it can be concluded that the Sri Lankan construction industry has proven the use of VE concept to MEP works to improve value for money regardless of the facts that the use of VE have to be developed more systematic and the awareness of the concept should be improved in order to get optimum use of the concept.

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Applicability of Life Cycle Assessment (LCA) to Buildings: A Review

Amarasinghe S.D.I.A.
University of Moratuwa, Katubedda, Moratuwa, Sri Lanka

Soorige S.D.A.
Lecturer, University of Moratuwa, Katubedda, Moratuwa, Sri Lanka

ABSTRACT
Life Cycle Assessment (LCA) is globally recognized as an analytical tool that systematically and holistically investigates, compiles and evaluates potential environmental burdens attributed with products, processes or an activity by ascertaining and quantifying material usage, energy consumption and environmental releases. LCA methodology has increased in popularity in developed countries in recent years as a decision making tool, to assess the buildings' environmental impacts and energy consumption throughout its entire life cycle. Even though, building LCA is accomplished internationally, it is hard to find evidence in the Sri Lankan context. LCA has come to a standstill in the industrial sector, as relatively less attention has been paid to the implementation of LCA to the building sector. Therefore, this study is aimed with the perspective of closing this research gap by conducting an investigation on the LCA implementation process, barriers and possible strategies of applying LCA to buildings, for the better adaptation of LCA into the Sri Lankan building sector.

Key Words: Life Cycle Assessment, LCA for Buildings, Life Cycle Inventory Analysis, Life Cycle Impact Assessment

1. INTRODUCTION

The perpetual development and anthropogenic activities that occur with the growth of the economic sectors has aroused public concern on undesirable environmental problems (Li & Ma, 2014). Therefore, it is required to implement methods to assess and alleviate the environmental impacts and resource consumption by different sectors (Höjer et al., 2008).According to Jeswaniet al. (2010), various measures are used to evaluate environmental emissions, such as Life Cycle Assessment (LCA), Ecological Footprint (EF), Material Flow Analysis (MFA), Input Output Analysis (IOA), Environmental Impact Assessment (EIA) and Environmental Auditing.

Out of numerous environmental assessment methods, LCA has been accepted as the only legitimate process to evaluate products, processes and services from the environmental perspective throughout the entire lifecycle (Arena & De Rosa, 2003).LCA can be defined as a systematic set of process which targets to quantitatively evaluate the potential environmental burdens affixed with product or process by recognizing and quantifying the environmental impacts and resource consumption. Moreover, LCA enables the quantification of cumulative environmental impacts attached along the entire life cycle from "cradle to grave" (Ortiz-Rodríguez, Castells, and Sonnemann, (2010). According to Chau, Leung, and Ng (2015), implementation of LCA is ruled by ISO 14040-14044 standards and the implementation process is structured into four fundamental steps, such as Goal and Scope Definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation.

Currently, LCA has demonstrated its capability to deliver an analytical framework to evaluate buildings' and industrial processes' environmental performance throughout its expected lifespan

(Utama&Gheewala, 2009). Extensive amount of LCA studies have focused on industrial processes (i.e. cement manufacturing process and paper production process) rather than on the building sector (Huntzinger& Eatmon, 2009). Accordingly, application of LCA to the building sector is relatively recent and novel (Buyle, Braet, &Audenaert, 2013) due to increasing attention to assess building performances over the entire life cycle (Tian, 2013).

2. LCA IMPLEMENTATION PROCESS TO THE BUILDING SECTOR

LCA implementation phases along with its different stages can be described in the table 1, which was developed based on the literature.

Table 1:- LCA methodology for Building Sector

Phase 1:- Goal and Scope Definition		
Requirements under the phase	**Method of achieving the requirements under the phase**	**Reference Code**
Defining goal of the LCA study	The goal of the extensive amount of LCA studies was to conduct a comprehensive assessment to realize potential environmental burdens and energy consumption of buildings across the entire lifecycle.	17,
Identification of Functional Unit	One square meter (1 m^2) of usable building floor area is the most common functional unit for the building LCA, which links all the flows of inputs and outputs, in line with the goal of the study.	30,
System boundary definition	It can be identified as cradle –to-grave (whole life cycle assessment) or partial lifecycle assessments, such as cradle-to-gate (building product assessment) and gate-to-gate (construction process assessment)	1,10
Identification of building lifespan	50 years has been used as the medium value as well as the commonly used standard building lifetime for the LCA study	33, 37,25
Presentation of assumptions	LCA based on the number of assumptions such as, all the waste was disposed to the landfills, 5% of materials have been wasted during the construction stage, transportation data is based on the average number of roundtrips from manufacture to site.	17
Presentation of limitations	Limitation of an extensive amount of LCA studies can be identified as exclusion of minor renovations and replacements (e.g. light bulbs, air filters, window glass, cleaning supplies, small electrical components, such as sensors and switches), interior decorations, local infrastructure impacts and site location characteristics due to the shortages in required data	17
Phase 2:- Life Cycle Inventory Analysis		
Identification of data collection method	Possible data collection sources are classified under different key building lifecycle phases, such as manufacturing phase, construction phase, use phase and EOL phase	1
Data collection	Typically LCI has identified upstream flows (raw material extraction, material production, transportation building construction and use), and downstream flows (deconstruction of building and disposal of building) which belongs to the system boundary of the study.	16
Calculation of collected data	Relevant flows of inputs and outputs within the defined system boundary has to be calculated in relation to the pre-determined functional unit	16
Phase 3:- Life Cycle Impact Assessment (LCIA)		
Selection of LCIA method	Selection of LCIA method (midpoint or endpoint) and impact categories has based on the goal and scope of the study.	8
Classification	Identified inputs and outputs in the phase of LCI, assigned into the numerous impact categories according to the influence which have been committed on the environment.	8
Characterization	Integrating impact categories to its category indicators.	24
Normalization	The most common normalization factor such as "person equivalents" which	4,5

	represents the amount of building emission with the mean value that is apportioned to each person of the population, from the selected region.	
Grouping and Weighting	Finally, significant impact categories are possibly ranked and prioritized by evaluating and comparing environmental impacts of different building lifecycle phases, according to its perceived severity of impact categories	4,5
	Phase 4:- Life Cycle Interpretation	
Identification of significant problems	Further identified significant issues, which have emphasized the highest contribution to environmental problems throughout the WLC by narrowing down identified impact categories into the most significant impact categories on the basis of the results of previous phases.	24
Evaluation of results	Results are evaluated and examined from the building point of view and, therefore, the energetic and environmental burdens of each building's life cycle can be determined	24
Uncertainty analysis and sensitivity analysis	Uncertainty analysis and sensitivity analysis are utilized to evaluate the robustness and strength of the conclusions.	8,10
Provide conclusions and recommendations	Present conclusion and recommendations for environmental improvements.	34

3. DRIVERS IN IMPLEMENTING LCA TO THE BUILDING SECTOR

The foregone review of the LCA implementation process has indicated inherent different drivers of LCA methodology to the building sector. Drivers are the factors that encourage the LCA implementation. Summary of literature findings about the drivers can be tabulated as given in table 5 with relevant references.

Table 2: Drivers for LCA implantation to the Building Sector

No	Drivers	Reference Code
1	To identify opportunities for environmental improvements	27,40
2	To recognize cost saving opportunities	14, 27
3	To promote environmental targets for buildings	40
4	To recognize energy saving opportunities	27, 29
5	To emerge and introduce the green products	14, 27
6	Top management pressure to implement LCA	14
7	To compare the environmental impacts of alternative materials that can be used during the construction process	27
8	For the purpose of meeting eco-labeling criteria	14, 27, 29, 40
9	As an initiative through Research and Development	14
10	As a novel instrument for Research and Development	14
11	As an environmental legislation or political pressure	14, 29
12	Due to the application of LCA by other competing companies	14
13	Growing industrial interest	14
14	High energy consumption of building sector	29
15	To acquire marketing benefits	40
16	Introduction of a Simplified LCA method	40
17	To acquire subsidies on environmental impact reduction	40

4. BARRIERS IN THE IMPLEMENTATION OF LCA TO THE BUILDING SECTOR

Application of LCA to the building sector, as a decision making tool has been constrained by numerous barriers. Table 2 shows the identified barriers with its respective literature source.

Table 3:- Barriers in Implementing LCA to the Building Sector

No	Barriers	Reference Code
Barriers in conducting LCA for the building sector		
A1	Lack of knowledge on the LCA as a decision making tool, which can be used to assess building lifecycle	3, 11, 26
A2	Financial difficulties in the implementation of LCA to the building sector	11, 27
A3	LCA approach for the building sector is viewed as less practicable by stakeholders	11
A4	Unavailability of one mythology to perform LCA	3,18
A5	Less organizational commitment to perform LCA	3, 11, 26
A6	Lack of high quality and accurate data to conduct LCA	3, 7, 4, 13, 15, 26, 27
A7	Barriers related to the co-ordination of LCA into the building sector	18, 11, 26
A9	Lack of LCA data with respect to the Building sector	3, 9, 13, 27
A10	Lack of cultural understanding of LCA for the building sector	3, 11, 26
A11	Lack of training and awareness related to LCA	3, 11,
A12	Lack of modern integrated management skills with respect to LCA	11, 18
A13	Limited understanding about the environmental impacts caused by the building sector	27
A14	Improper organizational structure	11, 18
A15	Less transparency of LCA tool	11, 18, 26
A16	Little interest by top management on the application of LCA	18, 26
A17	Limited customer demand to perform LCA	9, 18
A18	High cost of performing LCA	4,27
A19	Lack of governmental incentives	27
A20	Lack of professionals to conduct LCA	3,4, 27
A21	LCA for the building sector is more complicated than LCA for conventional products	7
A22	Difficulties in communicating results to the top Management	12
Barriers within the LCA method		
B1	Time taken to conduct the LCA	27
B2	Prejudices about the complexity of LCA method	4, 9, 27
B4	Number of assumptions used in the LCA study has led to uncertainties	8,
B5	No consideration of data related to the indoor environmental quality	23
B6	Lack of capability of including building site specific data to the LCA process	2
B7	Due to the subjectivity of selecting impact categories	7, 13,27
B8	High resource requirements and time consumption for the data collection	23,27
B9	The inherent subjectivity of LCA in Building structures	26, 27

5. Strategies to Overcome the Barriers of LCA Implementation to the Building Sector

As per the observations in table 3, it is revealed that there is a tendency towards less applicability of LCA to the building sector. This has been continuously highlighted. Hence, it is important to identify the strategies which can alleviate all barriers. According to Seidel (2016), facilitating and incorporating the application of LCA into the public policy might improve utilization of LCA, as a decision-making tool, which can ultimately lead to enhancing the environmental outcomes by means of supporting and stimulating sound decisions. According to Scheuer et al. (2003) the building sector is required to take an active interest in implementing public LCA software and databases by getting the support of the government. Further, according to them, the development of public LCA databases can accommodate valid LCI and LCIA data in an accurate manner for this purpose, eradicating difficulties faced during data collection. According to Cooper and Fava (2008), it is suggested to increase the industry and governmental funding on LCA software. Seidel (2016) stated that, stakeholders of the organization have to be educated and be made well aware about the LCA process and its prospective potential contribution to the organization. Singh et al. (2011) has suggested to integrate social indicators with the traditional LCA approach.Arena and De Rosa (2003) has highlighted that, traditional LCA technique requires more data as well as time and resource to perform. Hence, it is recommended to perform streamlined LCA practice that requires less data.

6. CONCEPTUAL FRAMEWORK FOR LCA IMPLEMENTATION IN BUILDINGS

LCA methodology has increased popularity in recent years, as a decision making tool in the developed countries and is used to assess adverse environmental impacts created by the building sector to the surrounding environment throughout its entire life cycle. Hamidul et al. (2015) specified that the building sector in developing countries is lagging in adopting LCA practices to their decision making process. Moreover, Ortiz-Rodríguez (2010) emphasized that LCA has come to a standstill in developed countries, as relatively less attention has been paid to the implementation of LCA in developing countries due to barriers pertaining to the implementation of LCA for the building sector. Therefore, these numerous views stress that LCA implementation and adaptation has been limited in the building sector, which needs to be exposed in order to add value to the industry. Thus, there is a requirement for developing a framework to facilitate the effective and successful implementation of LCA for the building sector. The conceptual frame work developed is shown as figure 1, which highlights the drivers, barriers and strategies to overcome the barriers in implement LCA for buildings.

7. SUMMARY

The LCA concept has recently emerged for the building sector with the contemporary push towards assessing environmental impacts. A significant application of building-related LCA is increasing in developed countries rather than in developing countries. Consequently, barriers in implementing LCA for building sector has been examined under two categories. Moreover, the study further reviewed the strategies that can alleviate the barriers in implementing LCA to the building sector. When it comes to the Sri Lankan context, as a developing country it is required to identify the practice of LCA in buildings.

8. CONCEPTUAL FRAMEWORK FOR THE SUCCESSFUL IMPLEMENTATION OF LCA TO THE BUILDING SECTOR

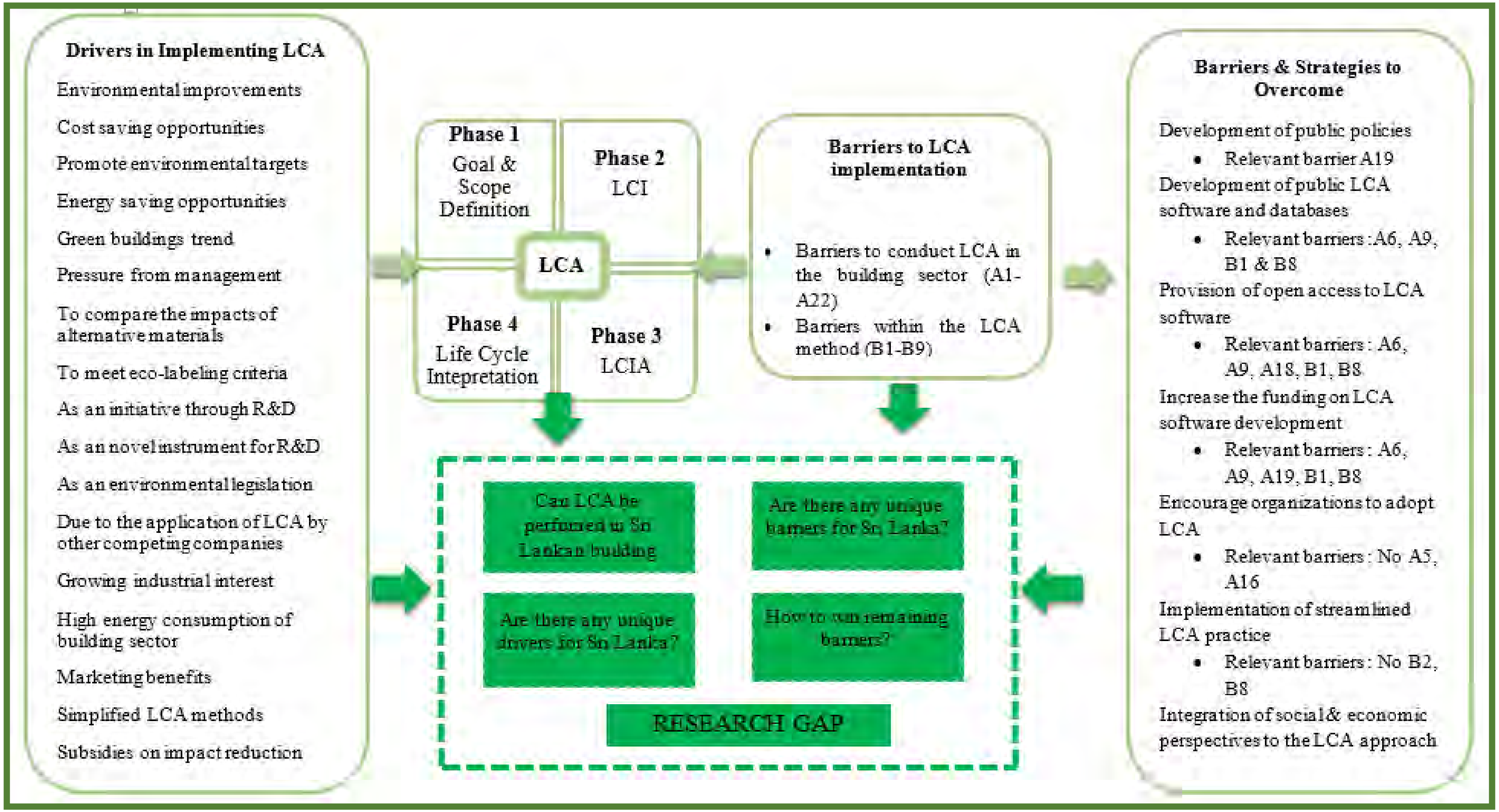

Figure 1: conceptual framework for the successful implementation of LCA to buildings

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Overcoming Barriers for Women in the Construction Industry: A Review

Kelly Mahaffy
East Carolina University, Greenville, North Carolina, United States,
mahaffyke15@students.ecu.edu

Syed M. Ahmed
East Carolina University, Greenville, North Carolina, United States,
ahmeds@ecu.edu

Chelsea Buckhalter
East Carolina University, Greenville, North Carolina, United States,
buckhalterc15@ecu.edu

Abstract

The U.S. construction industry has long been known to be a male dominated field. This is due to several reasons, including stereotypes that reflect deep-rooted ideas about women in the U.S. construction industry. In order for more women to enter the field, the construction industry needs to find a way to overcome the many barriers that stand in their way. The objective of this research is to provide an analysis of the Women Participation in Construction Model and to see if the model has been followed within recent years. The Women Participation in Construction Model proposes a solution to obtain and retain women within the construction industry.
The methodology used in this research is to collect data from a variety of sources, including professional journals, industry publications, construction industry leaders, construction industry organizations, and government records. Through literature and records review, information was gathered to help explain the state of the industry, highlighting women's issues. The collected data and model are combined, resulting in a series of suggestions for attracting, retaining, and promoting women in the construction industry.
The conclusions drawn from this paper provide an analysis of the Women Participation in Construction Model (WPCM) and women in the construction industry today and gives recommendations on how the construction industry can improve up following the model to better obtain and retain skilled female workers.

Keywords: Female Population, Construction Industry, Construction Management, Work Force.

1. Introduction

The construction industry has been facing an increasing crisis recently due to lack of available skilled workers. Demand for commercial construction has been high across the United States, with 93% of contractors expecting to see equal or greater profit margins in 2018. Despite demand, 60%

of contractors reported difficulty finding skilled workers in the third quarter of 2017 due to an ongoing shortage of skilled laborers (Donnelly, 2017). As the demand for labor is surpassing the supply, construction companies are turning towards a formally untapped source, women. It has long been known that there are not many women who work within the U.S. construction industry. This is due to many reasons, including stereotypes/sexism, lack of information available, physical strength, lack of daycare, flexibility of hours, a male dominated environment, and a lack of mentoring programs for women (Nielsen, Ahmed, & Yaris, 2013).

While there are many perceptions and reasons why the U.S. Construction Industry would not be a good fit for women, there are many industry job traits that should also attract a woman to the industry. Some of these include interesting and varied career opportunities, and the simple fact that women are a minority in which many firms want. Women offer a plethora of benefits for a construction company and give a unique perspective within the workplace. 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 companionate personalities, etc. (Nielsen, Ahmed, & Yaris, 2013). Another attraction for women to the construction industry could be that the gender pay gap is much narrower. In construction, women earn on average 95.7 percent of what men make (NAWIC, 2016).

These barriers preventing women from entering the industry has long hurt both females who would otherwise excel in a career in construction as well as the construction industry as a whole. Both women and the industry would greatly profit from more female workers pursuing a career in the construction industry. The 2013 article, "Women in the construction industry: Investigating current challenges faced by women in the U.S. construction industry," examined a possible solution to this problem by providing a model that shows ways in which to obtain and retain women within the industry. This model shows guidelines for educational as well as professional entities to recruit women, retain women, and increase personal growth within the construction industry (Nielsen, Ahmed, & Yaris, 2013).

2. Objectives of Study

Women as well as the construction industry would greatly benefit from more women entering the field. With the imminent need for skilled laborers in the industry, the field of construction needs women now more than ever before. The objective of this research is to provide an analysis of the Women Participation in Construction Model (WPCM) used in the 2013 article "Women in the Construction Industry: Investigating Current Challenges Faced by Women in the U.S. Construction Industry," and examine if it has been successfully used to obtain and retain women within the construction industry (Nielsen, Ahmed, & Yaris, 2013).

3. Methods

Data was collected from a variety of sources, including professional journals, industry publications, construction industry leaders, construction industry organizations, and government records. Through literature and records review, information was gathered to help explain the state of the industry, highlighting women's issues. Using a previously developed model, examples were found to show both successes and shortcomings within the industry for attracting and retaining women. The collected data and model are combined, resulting in a series of suggestions for attracting, retaining, and promoting women in the construction industry.

4. Analysis

Table 1: 2011 vs. 2016 NAWIC Facts

	NUMBER OF WOMEN		CHANGE	PERCENTAGE		CHANGE
Number of Women Total	828,000	939,000	**111,000**	828,000	939,000	**111,000**
Year	**2011**	**2016**	**5 Years**	**2011**	**2016**	**5 Years**
Occupation Sector Sales and Office	443,000	423,000	**-20,000**	53.5%	45.0%	**-8.5%**
Professional & Management	236,000	293,000	**57,000**	28.5%	31.2%	**2.7%**
Natural Resources, Construction & Maintenance	122,000	196,000	**74,000**	14.7%	20.9%	**6.1%**
Service Occupations	14,000	14,000	**0**	1.7%	1.5%	**-0.2%**
Production, Transportation & Material Moving	13,000	13,000	**0**	1.6%	1.4%	**-0.2%**

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 thousandth.

Table 1. illustrates a comparison of NAWIC's 2011 and 2016 statistics of women in construction. Table 2. illustrates that as of 2016, Women make up 9.1 percent of the construction industry in the United States. After an analysis of the changes between 2011 and 2016, as illustrated in Table 1., it appears substantial progress has not been made in accomplishing the goal the WPCM set forth, as presented in the 2013 article "Women in the Construction Industry: Investigating Current Challenges Faced by Women in the U.S. Construction Industry" (Nielsen, Ahmed, & Yaris, 2013). Further analysis of Table 1. provides that while the number of women working in construction has increased, the number of challenges faced by women in construction has not decreased. Long work hours, unequal pay, gender bias, and issues with work-life balance are just a handful of concerns that women in the construction industry must face (Morello, Issa, & Franz, 2018). Providing further analysis of each sector of the WPCM will show what has been followed within the past 5 years and what has not, leading to the current place women are at in the construction industry today.

Table 2: Women Participation in Construction Model

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

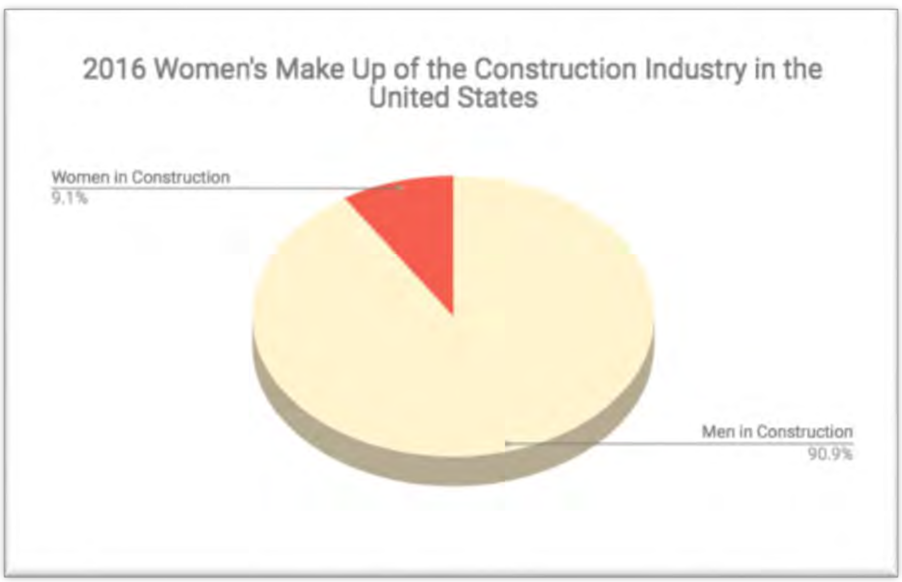
	Educate women on how to advance and promote themselves within the organization Try to increase female numbers to at least 15% Employ more women in leadership roles to can create motivation from within the company Offer more training programs and hands-on skill development for women Make young girls aware of opportunities for women in construction management as well as construction trades
Elementary and High School Education	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. Address the situation of lack of females within the industry and lack of awareness.
College and Educational Institution Sectors	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.

Source: Nielsen, S., Ahmed, S., & Yaris, C. (2013, July). *Women in the Construction Industry: Investigating Current Challenges Faced by Women in the U.S. Construction Industry*. Paper presented at the 2013 Creative Construction Conference.

The WPCM (Table 2.) identifies four sectors that must work together to increase the number of women working in the industry (Nielsen, Ahmed, & Yaris, 2013). The model suggests that early awareness of opportunities in construction, coupled with support from school administration and professional women's construction organizations, women will be more interested and confident working in the construction industry. When women enter the industry, employers can retain them by focusing on mentoring and ensuring availability of career advancement opportunities.

Outreach efforts for grade school girls are grassroots in nature. Companies, colleges and universities, and female-oriented construction organizations are leading efforts to promote careers in the construction industry, from high school all the way down to the elementary school level (Filtz, 2018; Stough, 2016). By working at the local level, companies can establish relationships with schools to promote construction careers for women. According to the WPCM, this effort to make girls more aware of the construction industry should be supported by school administration and professional women's construction organizations. Unfortunately, support from grade school administration still appears to be lacking. A study conducted by Mathew (2014) indicated that 21 out of 36 female students felt that their high school advisor had no influence on their decision to enroll in a construction management program, and two students indicated that their high school advisor had a highly negative impact. Several studies and working professionals (Bilbo, Lavy & Waseem, 2009; Caulfield, 2015; Crary, 2014; Lopez del Puerto et al, 2011) have highlighted the fact that high school counselors possess limited knowledge about construction programs and often carry a negative image of the industry. In some cases, counselors even discourage girls from entering the field because it is believed that it is not suited for them. A survey of 26 colleges and universities registered with the Associated Schools of Construction identified lack of promotion from high school counselors as a reason why women are not choosing construction management programs (Sewalk & Nietfield, 2013). Morello, Issa, and Franz (2018) conducted a survey questionnaire of 171 women working in construction-related occupations. The questionnaire was designed to collect information related to women's participation in recruitment and mentorship programs, perception of the industry, job satisfaction, and leadership and behavioral traits. Researchers focused on the timing of when women were first interested in construction and cross-tabulated the results with their plans to continue working in the industry. It was noted that women who became interested in construction after completing college were more often dissatisfied than the women who became interested in construction during childhood, in high school, or in college (Morello, Issa, & Franz, 2018).

A brief internet search will net a list of several professional organizations for women in construction, including: The National Association of Women in Construction (NAWIC); Women Construction Owners and Executives (WCOE); the Women Builders Council (WBC); and the National Association of Professional Women in Construction (PWC). While each organization may have a specific focus, all of them share the same basic goals: to recruit and promote retention of women in the construction industry, and to help women develop skills needed to advance in their careers. These organizations provide support through a variety of channels, including training and education, networking, and advocacy. Many successful women in the construction field feel that they could not have attained their positions without the support of an organization such as NAWIC or PWC (Freed, 2016). Morello, Issa, and Franz (2018) conducted a survey questionnaire of 171 women working in construction-related occupations. The questionnaire was designed to collect information related to women's participation in recruitment and mentorship programs, perception of the industry, job satisfaction, and leadership and behavioral traits. A majority of respondents (65%) indicated they had career mentors, and 81% of participants claimed membership in a women's organization or trade group (Morello, Issa, & Franz, 2018).



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 thousandth.

Figure 1: Comparison of NAWIC 2011 and 2016 facts

In 2011, women made up approximately 9 percent of the construction industry; women now make up about 9.1 percent of the industry, as illustrated in Figure 1. Many professionals in the field agree that the construction industry remains hostile to women (Crary, 2014; Filtz, 2018; Freed, 2016; Stough, 2016). As a result, companies are revising their mission statements and publishing position papers to show their commitment to recruiting and retaining women in construction (Balfour Beatty, 2017; March 2018). While these efforts may not have an immediate impact that dramatically increases the number of women working in the industry, the changes do appear to have some effect on women. Morello, Issa, and Franz (2018) found that women made up between 31 and 40% of the workforce and 31% of participants reported programs for recruitment and retention. Researchers determined that an ordinal association existed between the percentage of women in a company and the presence of recruitment and retention programs, indicating that companies with a higher percentage of women also have the highest usage of recruitment and retention programs. It should be noted that correlation does not indicate causation, so one cannot make the conclusion that the higher percentage of women in the company is caused by the recruitment and retention programs. Others report similar statistics, ranging from 34 to 40% (Filtz, 2018).

5. Recommendations

Currently, there exists a disconnect between the four sectors identified by the WPCM. This is problematic; for the model to function properly, all of the sectors must work together. Studies have shown that girls need to be exposed to construction early to become interested in it. Early exposure is likely to occur in one of two places: in the home or at school. Women working in the field have reported that they became interested in construction because one or both parents worked in the industry (Mathew, 2014). Not all girls will have a parent at home working in the industry, so it is necessary for school counselors to become more aware of the opportunities available for females in the field. Colleges and universities will need to become better advertisers of their programs and work with high schools to show the variety of career paths available to women in the construction industry. This will require cooperation and communication between faculty, staff, and administration at both high schools and colleges/universities.

Presently, there is a grassroots effort to recruit and retain women in the industry, led by women's organizations. As of now, this effort has not generated the growth results that would be expected, based on the overall growth of the construction industry. Women's organizations should help bridge the gap between grade schools and colleges/universities through career fairs and other outreach events. Women's organizations should continue to serve as advocates for women working in the construction industry, building relationships with employers to ensure that women are offered equal compensation for equal work, as well as opportunities to advance in companies. The number of campaigns aimed at attracting and retaining women in the field has increased; these efforts should continue. Employers should work with both women's organizations and schools to promote careers in construction.

Finally, and perhaps most importantly, the culture of the construction industry needs to change. Despite advances, sexism, discrimination, and bullying are still widespread problems in the industry. Companies need to address these problems and show that the behavior will not be tolerated.

6. Conclusion

If the U.S. construction industry wants to fix its labor shortage problem, it is essential that more women enter the field. This will be a hard feat to accomplish and will take much time and careful consideration, but it can be done. By utilizing all the sectors in the WPCM properly, the U.S. construction industry can successfully recruit, retain, and increase personal growth of women within the construction industry. This can only happen if all sectors of the WPCM are working together and the culture of the of the construction industry changes. With the labor shortage problem being one of the largest problems the U.S. construction industry faces today, it is time the industry starts taking its lack of gender diversity seriously and starts focusing on significant ways to fix it.

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Green Infrastructure: The Case for Low Impact Development in Coastal North Carolina

Amelia Saul
Graduate Student, East Carolina University, Greenville, NC, USA
saula12@students.edu.edu

Jonathan Chase
Graduate Student, East Carolina University, Greenville, NC, USA
chasej90@ecualumni.ecu.edu

Dr. Syed Ahmed
Professor & Chair, Construction Management Dept, East Carolina University, Greenville, NC, USA
ahmeds@ecu.edu

Abstract
For more than 40 years, North Carolina (NC) has focused on maintaining and improving the state's water quality with conventional best management practices (BMPs) to control runoff. Despite the widespread application of BMPs, the desired results for water quality have fallen well short of expectations. NC has lost more than 100,000 acres of shellfish waters to contamination in the last 20 years and continues to lose these most sensitive waters (Low Impact Development for the NC Coast, 2008). Meanwhile, Low Impact Development (LID), within the broader construct of Green Infrastructure, has been gaining traction as a more economical and environmentally friendly alternative to conventional BMPs. In addition to improved water quality and healthier aquatic habitat, the use of LID techniques offers other benefits including lower infrastructure costs through reduced maintenance demands, greater lot yields, increased property values, and reduced incidences of costly flooding events. Despite this outreach and other educational efforts, the state has seen a small voluntary shift from conventional management techniques to LID. An online survey was distributed to 78 management professionals that work in coastal NC, investigating the awareness of LID. The survey's results indicate a common knowledge of LID regardless of years' experience or profession-type. Respondents have a favorable impression of LID and, of those who used one or more LID techniques in projects, there is a preference to LID versus conventional management techniques when future use is considered. While the state wields the most influence over the future deployment of LID, more significant outreach and education are seen as critical to a deeper understanding and acceptance of LID.

Keywords
Green Infrastructure, Low Impact Development, Coastal NC

1. Introduction

Historically, water quality and runoff quantity have been the primary targets of comprehensive and conventional storm water management programs. Conventional storm water management programs move storm water away from its built environment and states, such as NC, insist developers use storm water best management practices (BMPs) to obtain necessary permits. Site-specific management techniques do not consider impacts to the surrounding watershed that, as water quality assessments in Coastal NC have shown, result in the continued degradation of water quality and the natural environment. The continued growth of

Coastal NC will only exacerbate already troubling water quality statistics and the health of the state's aquatic habitats. According to the US Census Bureau's 2016 estimates from counties in Coastal NC, population growth rates are expected to continue to grow with the region's population approaching 1.2 million in 2030, a 43 percent increase from 2000 (Kulik et al., 2008).

Dias, Wilson, & Henn (2016) describe management practices as Green Infrastructure (GI), which outlines a network of LID practices with the combined purpose of reducing runoff and improving water quality. GI was first promoted by environmental organizations and tested on university campuses. Today the success of these LID techniques in controlling runoff is now being recognized by municipalities across the country (Dias et al., 2016).

1.1 Establishing Definitions of GI and LID

According to the Environmental Protection Agency (EPA), LID is considered a "management approach." In addition to improved water quality and healthier aquatic habitat, the use of LID techniques offers other benefits including lower infrastructure costs through reduced maintenance demands, greater lot yields, increased property values, and reduced incidences of costly flooding events.

Further, the EPA currently uses the term GI to refer to the management of wet weather flows using these processes, referring to the patchwork of natural areas that provide habitat, flood protection, cleaner air and cleaner water. At both the site and regional scale, GI/LID practices aim to preserve, restore and create green space using soils, vegetation, and rainwater harvest techniques. LID is an approach to land development (or re-development) that works with nature to manage as close to its source as possible.

1.2 Evolution of Conventional Storm water Management, LID, and GI in NC

For more than 40 years, the State of NC has focused on maintaining and improving the state's water quality with conventional storm water best management practices (BMPs) to control storm water runoff. In a presentation of the *2007 Stormwater Programs Annual Report* (Reeder, 2007) to the Environmental Management Commission (EMC), Reeder suggested rules need adjusting in response to statewide shellfish closure data, statewide development trends, and the effectiveness of rules in developing watersheds. Presently, 2016 Census estimates the population of this region at 1,046,000 (Census.gov, n.d.) Kulik, Doll, & Putnam (2008) estimated continued population growth in NC's coastal counties, with the coastal county population expected to approach 1.2 million in 2030, a 43 percent increase from 2000.

Despite the widespread application of BMPs, the desired results for water quality have fallen well short of expectations. NC has lost more than 100,000 acres of shellfish waters to storm water contamination in the last 20 years and continues to lose these most sensitive waters (Low Impact Development for the North Carolina Coast, 2008). Water quality is especially important to the state's coastal communities, where clean water and a robust shellfish population are vital to NC's coastal economy. This contributed over a $32 billion to the state's total gross domestic product in 2013 (North Carolina's Ocean Economy: A First Assessment and Transitioning to a Blue Economy, 2017). Meanwhile, Low Impact Development (LID), within the broader construct of Green Infrastructure (GI), has been gaining traction as a more economical and environmentally friendly alternative to conventional BMPs.

2. Purpose Statement

The purpose of this research is to make a case for the use of GI and LID for management in Coastal NC. Knowing the shortcomings of conventional practices, researchers examined why, despite the different efforts of the NCCF and others, more practitioners in Coastal NC are not voluntarily using LID techniques versus conventional management methods. Furthermore, researchers examined what these specialists feel should be done to encourage more widespread application of LID techniques to work on improving water quality and the health of the state's shellfish population.

3. Methods

Despite the forty years that NC has mandated the application of conventional management techniques (BMPs) when developing sites, the sought-after resulting improvements in coastal water quality and the health of the coastal shellfish populations have fallen short of the desired expectations. With the arrival of GI/LID nearly 20 years ago and the push in NC, 10 years ago, many in NC hoped developers, engineers, planners, and academics would readily adopt these practices, which have proven to yield the results once sought from conventional techniques. The purpose of this study was to gauge the practitioners involved in management and design on an understanding of their knowledge and application of LID. Specifically, this study sought to identify the obstacles that exist that prevent more voluntary, routine, and consistent application of GI/LID techniques for managing coastal problems.

The Methodology section contains the following subsections: research method, participants, instrumentation, ethical considerations, procedures, and data analysis.

3.1 Research Design

The type of research method used in this study was quantitative research. The type of quantitative investigation pursued was non-experimental, descriptive design. This method was appropriate to the study since it aims to describe the present condition. The technique applied was a normative survey approach and evaluation. Given the period available to complete the research paper, a cross-sectional survey study was deployed.

One type of direct-data survey was included in this study – questionnaire survey. This format was preferred as it provided the researcher the ability to interact directly with each respondent. The question types varied to include multiple choice and open-ended to allow for meaningful commentary to gauge an individual's level of knowledge and involvement (or lack of) with GI/LID techniques, their perceived barriers to using GI/LID and whom they saw as having the most influence over design. The researcher used this type of research because this study focused on the perceived barriers to the more widespread application of GI/LID techniques. Thus, the descriptive method was most appropriate.

This survey research design was chosen for its cost-effectiveness, ease of administration, and access to information. Surveys using questionnaires are easier to administer and lend themselves to group administration. They also assure confidentiality and effective in providing information in a relatively brief time at a low cost to the researcher. They are widely used as a key tool for conducting management research and obtaining information about opinions, perceptions, and attitudes. The background characteristics collected from respondents enables answering the research questions on differences in practice and opinions on the future of advertising in the hospitality sector according to age, gender, and experience. (Writing Chapter 3: Methodology [for Quantitative Research]. n.d.).

Primary and secondary data were used in this study. The primary data resulted from the answers given by the respondents to an online survey developed by the researcher. The secondary data was through a review of literature that includes journals, reports, pamphlets and scientific conferences, presentations, and publications.

3.2 Participants

The target population of interest to this study was practitioners or others familiar with management in Coastal NC. The research sampling method used was non-probability purposive sampling. In purposive sampling, the researcher uses their expert judgment to select participants that are representative of the population (Conducting Education Research – Step 6: Select Sampling Technique, n.d.). The sample was developed based on the researcher's professional relationships (list of contacts) with developers, engineers, planners and others who work in Coastal NC. Regarding restrictions on the participant pool, the sample respondent had to either influence or be responsible for determining whether to use conventional or GI/LID techniques in coastal management design. Limitations were not provided in the sample. It was requested of the participants that the survey be forwarded to other colleagues that were involved or had an influence on decision making for practices in Coastal NC.

3.3 Data Collection

Two data collection tools were used for this study: 1) questionnaire and 2) secondary research – review of literature that includes journals, reports, pamphlets and scientific conferences, presentations, and publications.

The self-report questionnaire had 21 questions. The questions were a combination of structured questions (i.e. multiple choice (1), "yes" or "no" (2) and unstructured questions.

3.3.1 Recruiting the Sample

Initially, the researcher contacted perspective participants to let them know that they would be receiving an online survey from the researcher via Survey Monkey. Further, the researcher explained that he was a graduate student pursuing a Master of Construction Management from East Carolina University. The researcher told the sample that the survey was an essential part of completing his research paper - a requirement for graduation.

The consent of potential respondents was not obtained before distributing the online survey. Participants took an online survey by themselves, which they read to themselves and provided their answers. Participants were surveyed once and the average amount of time spent completing the survey was seven minutes.

4. Results

The online survey included a total of 21 questions. The questions were divided into the five following sections: 1) Socio-demographic information, 2) Knowledge of GI/LID, 3) Importance of LID practices, 4) Barriers to GI and LID, and 5) Facilitators for LID applications.

4.1 Socio-demographic information

The first section addressed socio-demographic information that include gender, education, profession, years of experience in the profession, years' experience in coastal design, implementation, regulation, and construction, professional licenses and certifications, and contact information for follow up questions if necessary. Of the 74 respondents, 74% of the participants were male and 26% were female. Ninety-five percent of respondents held a bachelor's degree or greater.

In order to understand the thoughts of those influencing the implication of LID practices, an online survey was delivered to 78 recipients, with further requests to share with other colleagues to include land developers, architects/landscape architects, engineers, planners, and regulators of management practices in Coastal NC. A variety of professions were well represented in the survey. Of the 74 participants, 25 identified as planners (34%), followed by 20 engineers (27%) and 14 who identified as being a regulator "Other" (19%) (Table 1). The largest portion of the respondents had 11-20 years' experience (38%) followed by those with 21-30 years' experience (32%).

Table 1: Type of Profession

Profession	*Number*	*Percentage*
Planning	25	34%
Other	4	19%
Landscape Arch	3	4%
Gov't Not Planning	14	19%
Engineer	20	27%
Developer	5	7%
Biologist	2	3%
Attorney	1	1%
Academic	2	3%

Years of experience in coastal management slightly differed from overall years in their respective professions. Thirty-three percent of the respondents had 11-20 years' experience in direct coastal management followed by those with 1-5 years' experience (28%). Eight of the respondents cited having zero experience in coastal management, which could correlate with lack of knowledge being a key impediment to LID implementation.

Several respondents had one or more certifications. Most respondents were either certified planning professionals (AICP's – 13) and Professional Engineers (PE's – 13). In NC, there is a LID certification process, whereas eight respondents were NCLID. Other certifications included (five – BMP certifications and six LEED professionals).

4.2 Knowledge of GI/LID

The second section of the questionnaire survey requested information regarding the participant's knowledge of GI/LID. Based on the data collected, 42% of respondents said they had common knowledge about the concept of GI/LID. Forty-six percent thought they had deep knowledge, and 13% called themselves an expert.

Table 2: Depth of Knowledge Regarding GI/LID

Answer Choices (with example)	*Response*	*Participants (#)*
No Knowledge (This is new to me)	0%	0
Common knowledge (Know about concept but have not seen it applied)	42%	30
Deep knowledge (Recommended strategy for storm water controls, etc.)	45%	33
Expert (Designed, installed, implemented, reviewed)	13%	9

The level of knowledge based on the profession was analyzed. The results indicated that 60% of planners said they had deep knowledge of GI/LID design among practitioners surveyed while only 40% of engineers felt this way. Respondents that identified as regulator-other, developer, or landscape architect described themselves as having common knowledge of GI/LID. Generally, engineers were most likely to describe themselves as having expert knowledge of GI/LID.

Respondents were asked if they discussed GI, specifically LID, with their team. Of the participants surveyed, 75% answered yes, 23% had never discussed (i.e., answered "no"). Researchers found that planners (34%) were more likely than other professions to have discussed GI/LID with their team followed by engineers (27%).

The respondents were also asked if they had applied LID concepts in their line of work. Of the individuals surveyed, 65% of respondents answered “yes”, while 31% said “no.” When looking at answers based off profession, researchers found that every biologist and academic professional that responded to the survey had applied or is applying LID techniques to their projects. Developers were the lowest where only 33% of respondents had used or are using LID. An average of 70 percent of planners, engineers, regulator – other, and landscape architects had applied or is applying LID to their projects.

Table 3: Practical Application of LID Concepts

Profession	*Applied LID*	*Have not applied LID*	*Participants (#)*
Planners	65%	35%	25
Engineers	75%	25%	20
Regulator- other	71%	29%	14
Landscape Architects	67%	33%	3
Developers	33%	37%	3
Biologists	100%	0%	2
Academia	100%	0%	2
Professional- other	60%	40%	5

4.3 Importance of LID Practices

The number one choice for the LID practice used in the past or in on-going projects was permeable paving, cited 49 times. When importance of LID practices was evaluated by the type of profession, 64% of planners believed LID practices to be important to projects, followed by 45% of engineers, and 35% of regulator-other. Although few developers responded to the survey, 67% thought LID practices were important to their projects.

As a follow up to the importance of LID to past or on-going projects, respondents were asked what percentage of their projects have incorporated GI/LID practices. The responses could be open-ended and varied greatly. Planners and regulator-other experienced projects that ranged from not incorporating LID at all to some that always incorporated LID. Engineers response differed slightly differed ranging from less than 5 percent to 75 percent. One developer noted that LID was used in 95 percent of their most recent projects and 100 percent in the retrofit of older properties.

Next, respondents were given a list of six LID practices and asked if they would apply any of these LID practices in the future; they could choose all practices that applied. The majority of respondents chose permeable paving, rain gardens, bioswale, cistern, and rain barrels. Vegetated roof was the least chosen option.

Respondents were then asked to rate their satisfaction with the use of GI/LID in their respective projects. More than half (52%) of the respondents said the use of GI/LID in their projects had satisfied/met expectations, while 6% of respondents noted their dissatisfaction with LID, and 20% were somewhat satisfied. Looking at responses based on profession, with the exception of developers, more than half of the respondents said that LID practices had impressed/met expectations.

Table 4: Impression of LID Practices by Profession

Profession	*Indicated “Impressed/Met Expectations”*	*Participants (#)*
Planners	52%	25
Engineers	50%	20

Regulator- other	57%	14
Landscape Architects	100%	3
Developers	33%	3
Biologists	0%	2
Academia	100%	2
Professional- other	60%	5

Respondents were also surveyed to determine the most common storm water practices. Among the choices given, wet pond, reduced impervious cover, infiltration system, and permeable pavement were chosen most often. Respondents did indicate experience with all the LID choices provided with vegetated roof being chosen the least often.

With the questions to follow, the focus shifted from GI/LID to conventional systems. The survey asked respondents to evaluate their satisfaction with conventional management (non-GI/LID) systems. Only 38% of respondents said the use of conventional systems in their projects satisfied/met expectations. The same number (38%) said they were somewhat satisfied with conventional systems while 8% said they were not satisfied at all/did not meet expectations. Only 5% said conventional systems impressed/exceeded expectations. Further comparison of satisfaction of LID versus conventional system based on respondents' professions determined that overall, most respondents were not as satisfied with conventional practices as compared to LID methods. When compared with their future use in projects the results are similar. Based on the responses, there is support for future projects for LID practices.

4.4 Barriers to GI and LID

The fourth section asked contributors their thoughts on barriers and obstacles to GI and LID. There were two questions in this section. The first question asked respondents to identify which barriers/obstacles they had found in implementing, reviewing, suggesting, and/or recommending LID practices. According to the survey results, respondents cited the following 4 barriers 1) construction costs of LID practices were too expensive, 2) geology/hydrology factors were not appropriate, 3) political (ex. community not in support of, fear of costs to developer), and 4) lack of incentives for the application. Of note, "lack of knowledge of the client" was cited 28 times as contributing to barriers to implementation of LID. Overall, the results indicate that a general lack of knowledge exists.

As a follow up to obstacles and barriers to LID, respondents were asked, based on their experience, which group they felt wielded the most influence over design. Thirty-five percent of respondents believe that the NC government wielded the most influence over design, followed by local government at 25%. Based on profession, overall, most planners, engineers, and regulator-other believed the state wields the most influence on design.

Table 5: Group Cited as Wielding the Most Influence on Stormwater Design by Profession

Group	*Planners*	*Engineers*	*Regulator-Other*	*Landscape Architect*	*Developers*	*All others*
Design Team	24%	10%	29%	0%	33%	22%
Developers	8%	10%	0%	33%	33%	11%
Clients	0%	5%	0%	0%	0%	11%
Local Government	20%	30%	14%	67%	0%	22%
State Government	28%	40%	50%	0%	33%	11%

4.5 Facilitators for LID applications

The last section of the survey included facilitators for LID implementation. Survey respondents were asked to choose programs and/or incentives that could be recommended to increase GI/LID application in Coastal NC. The results found that many respondents believe regulatory changes at the state level for LID versus conventional systems would increase GI/LID. Of the professions surveyed, planners held the most in-depth knowledge of LID practices, while engineers have the most expertise in LID design. Planners, engineers, biologists, academics, and professionals described as others discussed LID practices in the past when preparing for projects.

Table 6: Program Change and/or Incentive Necessary for LID Implementation

Program and/or Incentive	Number of Times Chosen
Regulatory changes at State level for LID versus conventional (grey) systems	43
Financial Incentive	36
Regulatory requirements at local level for LID versus conventional (grey) systems	35
Policy innovation	29
Education Programs	25
Design team education programs	24
Development team education programs	24
Workshops/Conferences	21
Marketing	15

5. Discussion

The purpose of this research was to examine the use of GI and LID for management in Coastal NC. Furthermore, researchers examined why management practitioners are not voluntarily shifting away from the use of conventional management techniques to GI and LID methods.

The survey was distributed to enlisted representatives including developers, architects/landscape architects, planners, engineers and other professionals who are involved in the decision-making process of the current or future development efforts within Coastal NC, to assess their opinions and perceptions on LID practices.

The findings from the survey show those involved in management decisions within coastal NC share a common knowledge of GI and LID techniques. Overall, planners held a deeper knowledge than their counterparts did whereas engineers had more expertise in LID design, installation, and use. Although common knowledge of LID was prevalent among the respondents, the instance of subsequent discussion of this topic and did not correlate with the knowledge; in fact, it dropped off. Ultimately, the actual application of LID methods because of common knowledge was even lower.

Survey participants were asked to assess the importance of LID practices to past or on-going projects. Most noted that LID was necessary for reasons such as meeting state requirements, fulfilling a local desire, meeting certifications (as in LEED or Green Building Council) and supporting environmental causes. Respondents were also asked to rate their satisfaction with the use of GI/LID for their projects. Most were satisfied with GI/LID and stated that it met their expectations. Only a few were dissatisfied with the results. When asked to compare satisfaction with LID versus conventional practices, respondents were not as enthusiastic. Overall, most respondents were more satisfied with LID in comparison with conventional methods.

Overall, the survey results demonstrated a general lack of knowledge on behalf of regulators, clients, and/or the design team. Beyond greater government involvement at the state level, planners also valued financial incentives followed by general policy innovation as ways to increase the use of LID techniques. Engineers answering the same question provided the same response noting change should occur at the state level. They also felt financial incentives would be a motivator. In contrast, those identifying as regulator-other, ranked greater education as the best incentive. Landscape architects were the only community of professionals to choose unanimously that change at the local level was the best form of incentive. Developers identified financial incentives, workshops/conferences, and education programs as tools that would increase the rate of LID implementation. Other professionals surveyed believe change should occur at both state and local levels equally, followed by marketing and education team programs.

6. Limitations

One of the limitations of this research study was the constitution of the sample. First, respondents were not randomly selected from a larger population to participate in the study. The researcher's professional relationships with most of the sample may have biased the sample or, at a minimum, favorably influenced the response rate. The sample was also not structured such that a pre-determined equal number of management practitioners were solicited based on their profession. Therefore, the response rate by profession could not be measured and, further, the results might have reflected a bias in that the perceptions of one or two professions stood out more than another profession only because the researcher, for example, knew more planners and engineers than developers.

Further, by allowing respondents to forward the survey link to a colleague, the researcher was not in control of the study's ultimate sample size. Another limitation was the structure of some of the survey's questions. For example, some of the questions could have been set up using the Likert Scale format but were not. Lastly, several questions also allowed respondents to "choose as many answers as applied" which prevented the researcher's from quantifying the importance (rank) of one answer over another.

7. Conclusion

After extensive efforts over the last few years, particularly the work of the NCCF and others, GI and LID have limped into the day to day fabric of practice in Coastal NC. Despite the efforts of the NCCF and the state's formal recognition that attempts to regulate and manage GI and LID has fallen short of expectations, resulting in shellfish closures and continued degradation of water quality, LID still struggles to be recognized as the preferred method for control.

To understand why such reluctance has occurred by applying LID over conventional methods, a survey was sent to those involved in practice in Coastal NC, to ascertain their opinions and perceptions over barriers and strategies surrounding LID. The overarching theme amongst those designing, regulating and managing LID was a lack of knowledge exists whether on behalf of regulators, clients and/or the design team. As a result, misconceptions over cost and usage in various climates and soils continue to plague LID's acceptance. Trinkaus & Clar (2015) stated that if there is no prior knowledge about LID, the implementation will never succeed.

A more troubling barrier to LID's implementation is the regulatory fragmentation around LID. Most recently with state legislative changes, the state is in charge of management. Affirming the state's role in management, survey respondents believed the state wields the most influence over management and is a catalyst for making the change to LID.

Experts tend to agree there are strategies in place that make a case for LID. First, the benefits of LID are understated. Further, LID can be applied in a variety of climates and soil types. Eight case studies found that LID projects cost 19 percent less on an average capital construction cost basis and could provide up to 20 additional benefits beyond water quality than traditional designs (Forasté, et al., 2011).

In making a case for LID, Trinkaus & Clar (2015) stated that with any document, the information needs to be well-defined for users. The information needs to include specifics as to why the changes are being made (Trinkaus & Clar, 2015). However, change sometimes needs a nudge. A widely accepted practice among many is providing incentives for modifying management behavior. The results from a most recent survey conducted by the NAHB shared that home builders would be much more likely to adopt low-impact or more sustainable management practices if local jurisdictions offered fast-track permitting or other incentives for installing them (Birk, 2017). Partnering with the idea of incentives, Nattress (2017) ended with good advice and believes communication is important for green efforts. Many believe that in order to have effective water resource management, local governments, businesses, community organizations, and residents need to work together and adopt integrated approaches to impacts (UNHSC, 2011).

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Causes of Fall of Person from Height Accidents on Building Maintenance and Repair Elevated Works in Hong Kong

Abid Nadeem
Assistant Professor, School of Engineering, Nazarbayev University, Astana, Kazakhstan
abid.nadeem@nu.edu.kz

Y. N. Johnny Mok
Former Lecturer, HKUSPACE, The University of Hong Kong
johnnymok.us@gmail.com

Abstract

Fall of Person from Height (FPH) is one of the main causes of accidents on construction sites and its accident rate is at the highest rank in Hong Kong. Therefore, this paper investigates into the causes of the FPH accidents and recommends possible solutions to tackle the deficiencies on the present safety management of building maintenance and repair elevated works. The information and data of the research project were collected through literature review and the questionnaire survey. The literature reviewed hazards and safety measures of maintenance and repair elevated works. A semi-structured questionnaire searched the opinions from 103 respondents for their views on safety measures of the building maintenance and repair elevated works. The results showed that the most important causes of accidents were the lack of sufficient knowledge of workers about safety, lack of safety training, improper communication, incompetent supervision, lack of work related training and not meeting the statutory requirements regarding the working platforms, safety management system and minor works control system.

Keywords

Construction Safety Management, Building Maintenance Works, Repair Elevated Works, Construction Accidents, Hong Kong

1. Introduction

Hong Kong's construction industry in the buildings sector has developed significantly since 1950s. There are now many buildings more than 50 years old in Hong Kong. The demand of maintenance and repair works of these old buildings has increased tremendously in recent years. This is true for both the high-rise and low-rise buildings in the public and private sectors. Many industrial accidents in recent years have occurred on these works. For building maintenance and repair elevated (BMRE)works, bamboo or metal scaffolds, tall ladders and gondolas are the common means for working at height in Hong Kong. Every year, considerable numbers of workers are subject to injuries and even death when using these means during such works. Fall of persons from height (FPH) is the one of the 23 different types of construction accidents in Hong Kong which has a high fatality rate. The data in Table 1 shows that over the 10-year period from 2007 to 2016 for which complete data is available, there is no real decrease in the accident and fatality rates on construction projects in Hong Kong. While the FPH accident rate is almost steady between 9 and 14% of total number of accidents, the fatality rate is much higher between 35 and 79%. This shows that the efforts in Hong Kong towards improving safety performance in the construction industry are not very effective. These efforts include promulgating health and safety in workplaces via training, promotion, legislation, etc. to improve the safety awareness and performance of workers and employers. In response to the above, the objective of this paper is to explore the situation regarding the safety management processes to understand the most important needs of safety requirements. It reviews the deficiency of current safety management system and seeks for improvements in the existing safety circumstances of BMRE works to minimize or even eliminate any reoccurrence of accidents.

Table 1: Industrial Accidents in Construction Industry of Hong Kong (2007 – 2016)

Year	All accidents	FPH accidents	All fatalities	FPH fatalities	FPH accident percentage	FPH fatality percentage
2007	3042	360	19	9	12%	47%
2008	3033	388	20	8	13%	40%
2009	2755	397	19	15	14%	79%
2010	2884	406	9	6	14%	67%
2011	3112	390	23	10	13%	43%
2012	3160	423	24	12	13%	50%
2013	3232	431	22	15	13%	68%
2014	3467	372	20	7	11%	35%
2015	3723	376	19	9	10%	47%
2016	3720	349	10	7	9%	70%

Source: Data extracted from Labour Department of Hong Kong website: http://www.labour.gov.hk/eng/osh/content10.htm

2. Literature Review

2.1 Means of FPH Accident Prevention

For the prevention of FPH accidents for BMRE works several means are used. Additional attention is required on the safety performance of building maintenance and repair elevated (BMRE) works. The tendency to hire relatively low-skilled workers on BMRE works is high. BMRE works are not subject to the same stringent statutory safety requirements as are for new construction (NC) works. FPH accidents are rather frequent in BMRE works. Despite using different techniques and safety measures, it has been observed that these measures are not effective to lower the fatality rate in BMRE works (Chan, et al. 2005). Several factors related to the technology of BMRE works contribute towards FPH accidents.

Truss-out bamboo scaffold is commonly adopted in BMRE works at external wall. FPH accidents usually are related to erecting, using and dismantling this kind of scaffold (Chan et al., 2008). Therefore, safety procedures for using bamboo truss-out scaffold were introduced in Hong Kong (Labour Dept., 2001a). To replace bamboo scaffolds, metal scaffolds can be adopted in BMRE works. To ensure the safe use of the scaffold, provision of proper design, selection of reputable contractor, employment of competent person and examiner for erection and dismantling, provision of site supervision and management shall be considered (Labour Dept., 2001b).

In Hong Kong, suspended working platform or gondola is also frequently used in building maintenance and repair elevated works, such as cleaning window and renovating external walls. They must be installed and dismantled by competent persons, supervisors and workers (Labour Dept. 2001c). Elevated working platforms are also widely adopted for works needed to be carried out at high level, for example, E&M installation, maintenance or repair works. For safe use of the platforms, their maximum elevated height and capacity for loading, the workplace restriction, provision of trained workers and adequate supervision, regularly checking of the platforms, etc. shall be carefully considered (Labour Department, 2008).

FPH accidents are also related with the use of ladders. For the use of ladder, type of application, nature of ladder, need of safety precautionary measures and even the provision of training should be considered to ensure these can be used safely (Roughton and Mercurio, 2002). It is also a common kind of tool when carrying out BMRE works. Another means which is used in BMRE works are the safety belts and anchorage systems. Before choosing a suitable safety belt, risk assessment for the workplace should be done by proprietor and contractor. It is vital that if anchorage or fall arrest system is adopted, the system must provide continuous protection to the users throughout their operation. Many accidents for building maintenance and repair elevated works have occurred due to incorrect provision of the system.

2.2 Regulations for FPH Accident Prevention

Staring from 31 Dec 2010, the Buildings Department of Hong Kong Special Administration Region Government has fully implemented the Minor Works Control System (Buildings Department, 2011) which was launched to assist public to conduct minor works legally via simplified procedures to improve safety performance on such works (Buildings Department, 2010). Many of these works are related to external walls of buildings in which there are many threats for the occurrence of FPH accidents. A proper health and safety training and management is required to be enforced to conduct such works safely and to promote relationship between workers and project managers. Proper fall arrest system shall be also offered at the workplace to further reduce the safety risk for workers (MacCollum, 2007).

Under the Occupational Safety and Health (OSH) Ordinance (HKSARG, 1997), employers have liability on the health and safety of their employees. They must provide adequate supervision, instruction, information and training, and safe workplace, such as safe access and egress. Regarding the health and safety responsibility of employees at work, the OSH ordinance requires them to co-operate with their employer, who has reasonably set up health and safety requirements on them, and take care of others.

According to the HKSARG (2000) , contractors or proprietors of certain industrial undertakings should fulfil the development, implementation and maintenance of safety management system that includes 14 specific elements, which are safety policy, organizational structure, safety training, in-house safety rules, inspection programme, hazard control programme, accident/incident investigation, emergency preparedness, evaluation, selection & control of sub-contractors, safety committees, job-hazard analysis, safety and health awareness, accident control & hazard elimination and occupational health assurance programme.

Employer also has liability to regularly repair and maintain those machines and equipment in workplace were in safe condition (Lee, 2011). The repair and maintenance works should be done by competent person, who had received sufficient training and experience. Health and safety promotion is other essential element in safety management. Lee (2011) suggested numerous posters promulgating health and safety should be displayed at prominent locations of workplace to enhance safety awareness of both employer and employees.

In Hong Kong, multi-layer subcontracting system is adopted in majority of construction projects. As result, Fang et al. (2006) stated that safety performance of subcontractors was the vital part to ensure health and safety in construction sites. The subcontractor workers should obey the health and safety requirements, which were reasonably set up by main contractor. Also, subcontractors should cooperate with each other to help main contractor on implementing on-site health and safety.

2.3 Summary of Literature Review

This brief literature review highlighted the current means and regulations of preventing FPH accidents of BMRE projects with emphasis on Hong Kong's conditions. The findings from this review are the basis of the design of the questionnaire survey the results and analysis of which is presented in the following sections.

3. Research Methodology

In this paper, the research methodology explored the underlying issues of descriptive research which were investigated using the literature review and the questionnaire survey. Literature review findings were used to develop the survey questionnaire and to provide background material for evaluating the survey results. Questionnaires were distributed to 140 respondents along with a letter of request via email or by direct delivery of the survey form. The target respondents were chosen from different levels of building maintenance and repair work field, which included workers, project supervisors, project managers from contractors and subcontractors as well as technical officers and property managers of property management companies. It took about three weeks to collect 103 responses. Responses to survey questions were analyzed on aggregate basis. No distinction of responses was made among responses from various types of responders. This provides support to the consensus-based answers to the survey questions.

The survey included 16 safety related questions divided into three main categories namely, (1) safety implementation from question 1 to 9, (2) safety improvement from question 10 to 13, and (3) safety promotion from question 14 to 16. The responses to the questions were measured on a five-point Likert scale including strongly agree, agree, neutral, disagree, and strongly disagree. The 17th question was the open-ended question for any comments and recommendations by the responders. To obtain objective outcomes, the responses were assigned with numbers from 5 to 1 corresponding to verbal scales from strongly agree to strongly disagree respectively. The weighted average of the responses was calculated based on these numerical scales and the frequency of each response. The main phrases of the questions are presented in Table 1 along with the analysis of responses.

4. Results and Discussions

4.1 Purposes of Survey Questions

For the questions number 1 to 9, the purpose is to find out the present status of safety management system (SMS) that workers implement for BMRE works. Questions number 10 to 13 aim to acquire comments on control scheme which is being used to make improvement on the safety management system of BMRE works. The last three questions from 14 to 16, aim to get opinions on the safety promotion, which should be able to reduce number of accidents in the BMRE works.

4.2 Reponses to Survey Questions

The weighted average column in Table 2 shows the relative importance of the factors towards safety of BMRE workers with an emphasis of FPH accidents in Hong Kong. The Rank column further clarifies the importance of the factors. Going by these numbers, the most important six factors are (1) the need for safety promotion by government for BMRE works, (2) having award and penalty scheme to improve safety, (3) workers not knowing well about safe working platform use, (4) consensus that the FPH is the main type of fatal accident in BMRE works, (5) lack of knowledge by public to employ qualified BMRE contractors (factor 14), and (6) the importance of communication among work team member for arresting the occurrence of FPH accidents. While these were the six most important factors. The next three factors were also important as their scores were at least 3.92 which is just above average score of all factors. These factors are (1) not implementing well the safety management system, (2) below average quality supervision of workers and (3) insufficiently trained workers.

Table 2: Analysis of Factors affecting the Safety in BMRE Works

No.	Factors	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	Weighted Average	Rank
1	FPH is the main type of fatal accidents	36	58	7	2	0	4.24	4
2	Workers do not have sufficient safety training	27	49	21	4	2	3.92	9
3	Workers not know well about PPE use	9	53	23	11	7	3.45	14
4	Lack of fall protection equipment	5	39	28	21	10	3.08	16
5	Workers not implement well safety management system	34	55	8	4	2	4.12	7
6	Workers not know well about safe working platform use	47	43	6	4	2	4.26	2
7	Workers are not notified well about work place hazards	22	48	19	9	5	3.71	10
8	Workers lack awareness of safety measures	20	37	23	15	8	3.45	14
9	Reduce FPH accident risks by improving communication	40	43	18	2	0	4.17	6
10	Lack of workers' supervision	34	42	19	11	0	3.93	8
11	Need monitoring system for BMRE workers	30	36	20	10	7	3.70	11
12	Need control system for BMRE contractors	27	33	22	16	5	3.59	12
13	FPH accidents could be reduced by MWCS	29	30	19	16	9	3.52	13
14	Less realization of liability for employing BMRE contractors	33	63	5	2	0	4.23	5
15	More safety promotion by government for BMRE works	60	40	3	0	0	4.55	1
16	Having award and penalty scheme to improve safety	41	50	8	3	0	4.26	2

The minimum score of these factors is 3.08 which is more towards agreement to the factors asked in the questions. This shows that the factors are holistically important, and their ranks are just relative to each other. For example, the three least important factors (in relative terms) are (1) the lack of fall protection equipment, (2) workers not knowing well about PPE use, and (3) workers lack awareness of safety measures. All these three relatively least important factors are important as shown by their weighted scores. Figure 1 graphically shows the range of weighted scores of all the 16 factors considered. The variation of the weighted scores is quite small with standard deviation of 0.4 and co-efficient of variation of 10%. The mean value is about 3.9. Together, these statistics confirm that all factors considered are important and their importance ranks are only relative.

The responses from the 17th question was open ended. The responders commented on the enforcement of compulsory specialised safety training to contractors' employees who work at height. This training should be provided in both large and small-scale contractors and be refreshed once every three years. Only those contractors should be employed which provide safety training to their workers and can provide such records for confirmation. The current safety management system proposed by the government for general construction projects should also be enforced on BMRE works. Appropriate safety training should also be for the supervisory staff and management personnel. Award and penalty scheme shall be provided not only for workers and contractors but also for the property management company.

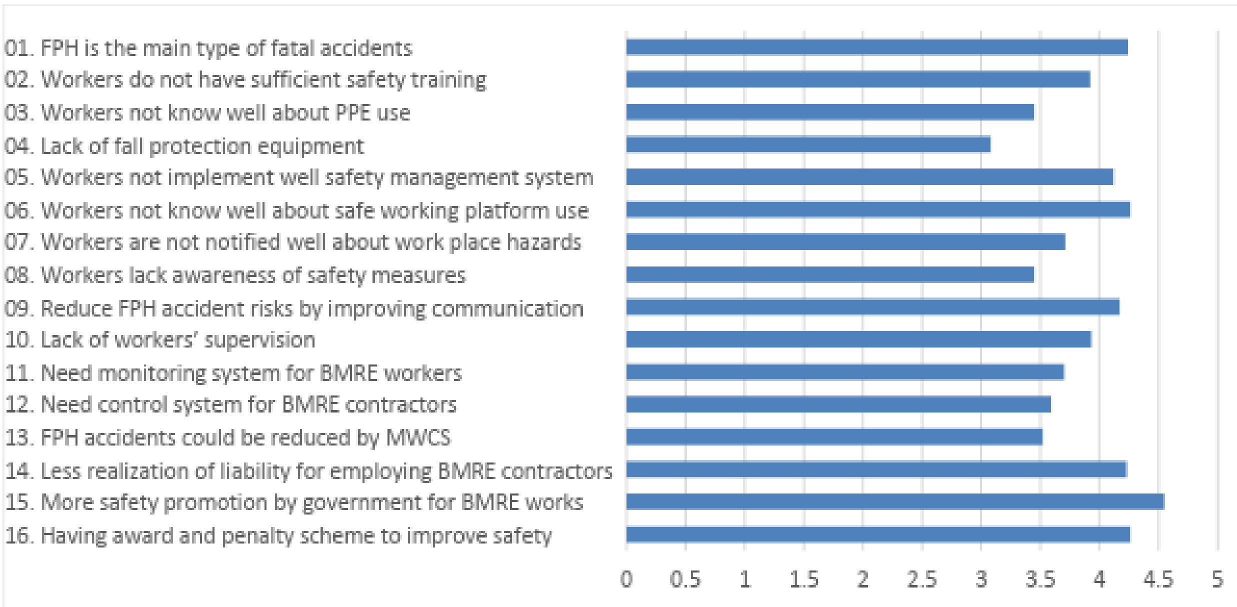

Figure 1: Weighted Average of Factors affecting the Safety in BMRE Works

4.3 Discussion of Research Results

The factors affecting the safety performance on BMRE works with respect to FPH accidents are logical and have an intuitive appeal towards their suitability. Other researchers have also investigated such factors and invariably there are similarities and differences in the results of this study and other studies. Chan et al. (2008) identified a proper safety management system, suitable working platform, regular safety training, suitable fall arresting system and maintaining a safe work place as the five most important factors. All these factors have been considered in this study as important factors. Nadhim et al. (2016) identified several factors which include the risky activities, individual characteristics, site conditions, organization/ management, means/tools, weather, and environmental conditions to affect such accidents. Many of these related factors have been considered in this paper. Hu et al. (2011) identified twenty factors from a broad review of literature. The five most important factors were the working surfaces and platforms, worker's safe behaviour and attitudes, construction structure and facilities, contractors' level safety intervention and worker's age.

From the results of this paper, more safety promotion by the government and the award/ penalty scheme was highly emphasized by the responders of questionnaire survey. By such actions, safety performance can be improved as the workers would consider safety aspects as integral part of their tasks and would have incentive to adopt safe practices and tendency to deter unsafe practices. This in turn will help workers understand well about the safe use of the working platform. The building clients will understand well the importance of employing competent contractors for BMRE works. One can expect competent work teams having good intra-team communications which is one of the important element identified for safe work practices in BMRE works.

The importance of implementing the safety management system cannot be underemphasized of which proper monitoring, supervision of workers, and their training are important components. Once a proper work supervision mechanism is set up, the workers can get right instructions for the safe performance of hazardous BMRE works. In addition, a separate but more importantly the specific control system in the form of minor works control system (MWCS) provides a much-needed support framework for such kinds of woks being distinguished from regular large-scale construction projects. Last but not the least, the role personal protection equipment, the fall prevention gears and other common safety measures is generally not well understood. That's why many accidents happen not because those measures were not provided to workers but because workers either did not apply these measures in correct ways or workers did not have complete knowledge about how to correctly use those measures.

5. Conclusions

According to the review and analysis on the past accident data of the construction industry in Hong Kong "Fall of Person from Height" is one of accident causes with highest fatal accident rate. Even though the figures do not indicate they referred to BMRE works, it can be concluded that workers need to face very high risk when they work at height. According to the research findings, the vital factors which cause FPH accidents are as follows:

1. Workers do not have sufficient knowledge about the utility of safe working platform.
2. Workers, who are required to work at height, did not receive adequate safety training and are not particular to wear safety harness with fall arrester.
3. Communication was inadequate in the work teams.
4. Workers lack enough supervision by a competent person.

Nevertheless, feasible policy and strategy can be identified and executed to further improve the present safety management on BMRE works. Such policy may include:

1. Proper scheme, such as minor works registration contractor scheme, for all scales of building maintenance and repair contractors can be mandatory to enhance the control under the government.
2. Government can put more efforts and resources to enhance the safety promotion on the importance of working at height safely.
3. An incentive system or attractive award system can be established to encourage contractors and workers to improve their safety performances.

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An Investigation into Interpersonal Conflicts in Post-Contract Stage of Sri Lankan Construction Projects

Aparna Samaraweera
Lecturer, University of Moratuwa, Katubedda, Sri Lanka
aparnas@uom.lk

Y.G. Sandanayake
Senior Lecturer, University of Moratuwa, Katubedda, Sri Lanka
ysandanayake@uom.lk

S.A.M.S. Wijerathna
Graduate Student, University of Moratuwa, Katubedda, Sri Lanka
manojsandaruwan17@gmail.com

Abstract

Construction project organisational context follows a temporary multi organisational approach with number of different parties involved, interacted and depended on each other. Due to such complex nature, interpersonal conflicts are inevitable in construction projects. These interpersonal conflicts affect project outcomes both positively and negatively. Hence, the aim of this research is to investigate the interpersonal conflicts in post-contract stage of Sri Lankan construction projects. This research aim was approached through a quantitative survey research design by using a structured questionnaire as the data collection technique. Questionnaire consisted of questions to analyse data using Analytic Hierarchy Process and a Likert scale to analyse data using the 'mode' value of the responses. Data were collected from a purposive sample of 30 professionals in Sri Lankan construction industry. Findings indicate that task conflicts are the most experienced type of conflicts than process and relationship conflicts in post-contract stage of Sri Lankan construction projects. 'Conflicts on resource distribution' is the most experienced sub type of interpersonal conflicts. The most experienced positive influences of interpersonal conflicts consist of: 'force to take better managerial decisions', 'introduction of creative solutions to problems' and, 'increase of the ability to give and receive constructive feedback'. The most experienced negative influence of conflicts includes its contribution to delays in projects. These findings are important for construction professionals for better management of human resources in construction projects.

Keywords

Construction Projects, Process Conflicts, Relationship Conflicts, Sri Lanka, Task Conflicts

1. Introduction

Personal relationships are crucial in achieving goals in organisations. Complexity of personnel, variety of goals, uncertainty of activities and intensive of capital are certain unique characteristics that set up a path to arise interpersonal conflicts in construction project organisations (Zhang and Fan, 2013). According to Leung *et al*. (2005), conflicts occur during construction stage due to new entrance and change of project participants. Construction project teams consists of different professionals and number of different parties such as contractors, suppliers, engineers, architects and quantity surveyors. Therefore, interpersonal conflicts in construction project teams are inevitable (Zhang and Huo, 2015). In generic terms, interpersonal conflicts are identified as a dynamic process that occurs between parties, who are in interdependent relationships, when they experience negative emotions over disagreements and obstructions in realising the set goals (Barki and Hartwick, 2004). However, Interpersonal conflicts are considered as a crucial factor for project performance (Zhang and Huo, 2015). Project based management is associated with complex situations. In a project, various parties operate simultaneously and collaborate within a network. Thus, relationship between those parties create fundamental influence in successful project (Kärnä and Junnonen, 2016). Managers have to deal with conflicts between their subordinates nearly 30-42 percent of their managing time (Brockman, 2014). Therefore, managers should identify the importance of interpersonal conflicts in construction projects.

Several researches have been carried out in the area of interpersonal conflicts in construction industry. Such studies have identified key conflict types and how those conflicts affect to the performance of construction projects (see Brockman, 2014; Zhang and Huo, 2015). It is identified that patterns of conflicts are changing time to time and necessary to examine frequently (Jehn and Mannix, 2001). However, most of the conflict studies have focused on individual level than group level (Way *et al*., 2016). Similarly, Sri Lankan researches also have focused on conflicts in construction context. Many such researches have focused on general construction conflicts, which are occurred in construction industry (see Nissanka, 2017; Rameezdeen and Gunarathna, 2003). General construction conflicts can arise due to internal, external, social, economic and political factors (Moura and Teixeira, 2010). However, apart from general conflicts, interpersonal conflicts also generate during the construction process in Sri Lankan construction industry (see Senaratne and Udawatta, 2013). Further, relationship conflicts, which are a type of interpersonal conflicts include disagreements on values, norms, or personal tastes of group members (Medina et al., 2005). These disagreements on cultural aspects urge the necessity of carrying out localised conflict studies to Sri Lankan context. This is because cultural specificity is identified across national boundaries (Kumaraswamy *et al*., 2002). Considering the facts cited above, this research aims to investigate the interpersonal conflicts in post-contract stage of Sri Lankan construction projects. This aim carries the objectives of prioritising different types of interpersonal conflicts and identifying the positive and negative influences of such interpersonal conflicts.

2. Literature Review

2.1 Types of Interpersonal Conflicts

In generic organisational context, conflicts arise when personnel in the organisation compete for scarce resources (Henry, 2008). Thompson (1990) indicates individual characteristics such as; personality, anger, stress have an effect on conflicts. In addition, interpersonal factors such as perceptual interface, communication, behaviour, and structure are guided to generate conflicts (Wall and Callister, 1995). Interpersonal conflicts among any group members can be categorised under three main types of conflicts such as; relationship conflict, task conflict and process conflict (Jehn and Mannix, 2001) described as follows:

Relationship conflict - Relationship conflicts happen due to disagreement among group members about personal issues (Wit *et al.*, 2012). Personal issues such as dislike other group members, feeling tension and frustration consist of relationship conflicts (Jehn and Mannix, 2001). According to Peterson and Behfar (2003), relationship conflicts negatively affect to group performance. When there is a conflict situation among group members, they mostly focus on each other's requirement rather than the organisational goals. Thus, it results in mutual hostility among group members and cause conflict escalation. Disagreement may raise due to interpersonal differences and it includes conflicts that are centred on personality differences (Senaratne and Udawatta, 2013). Many researchers have identified interrelations among relationship, task and process conflicts. According to them, task and process conflicts could result in relationship conflicts (Leung et al., 2005; Passos and Caetano, 2005).

Task conflict - Task conflict can be defined as disagreements among group members about task being performed during organisational operations (Wit *et al*., 2012). It relates to conflict about different opinion and different ideas about the same task. According to Senaratne and Udawatta (2013), the most understandable task conflict in construction industry is related with time, cost and quality of projects. Resource allocation can be identified as another source of task conflicts because, competition for resources such as personnel, facilities, plant and equipment, materials may escalate disagreement between group members (Wall and Callister, 1995). Conflicts on interpretation of facts and disagreement about decisions too resemble task conflict (Passos and Caetano, 2005). Generally, better decisions will be made about some problems aftermath of a task conflict, giving a positive effect on organisational performance (Simons and Peterson, 2000).

Process conflict - This type is about how task accomplishment should proceed in the working group and which member is responsible for which activity and how responsibilities should be delegated in organisations. When group members are unhappy about responsibilities, which are divided among group members will give rise to process conflict (Jehn, 1997). Process conflicts represent coordination activities within group such as decisions about logistical accomplishment of tasks and decisions about member coordination to succeed tasks (Behfar *et al*., 2011). Jackson *et al.* (2002) indicate process conflicts as any conflict over time scheduling and meetings, work approaches/methods or workload distribution among members.

Based on the above comprehensive literature review, main three (03) types of interpersonal conflicts (relationship, task and process) and sub types of main interpersonal conflicts have been identified. Following such analysis, most experienced interpersonal conflict type selection hierarchy for construction industry was developed as in Figure 1. Given the ambiguity surrounding the terminologies used by various authors and experts, the best judgment has been made to identify the sub types of main interpersonal conflicts.

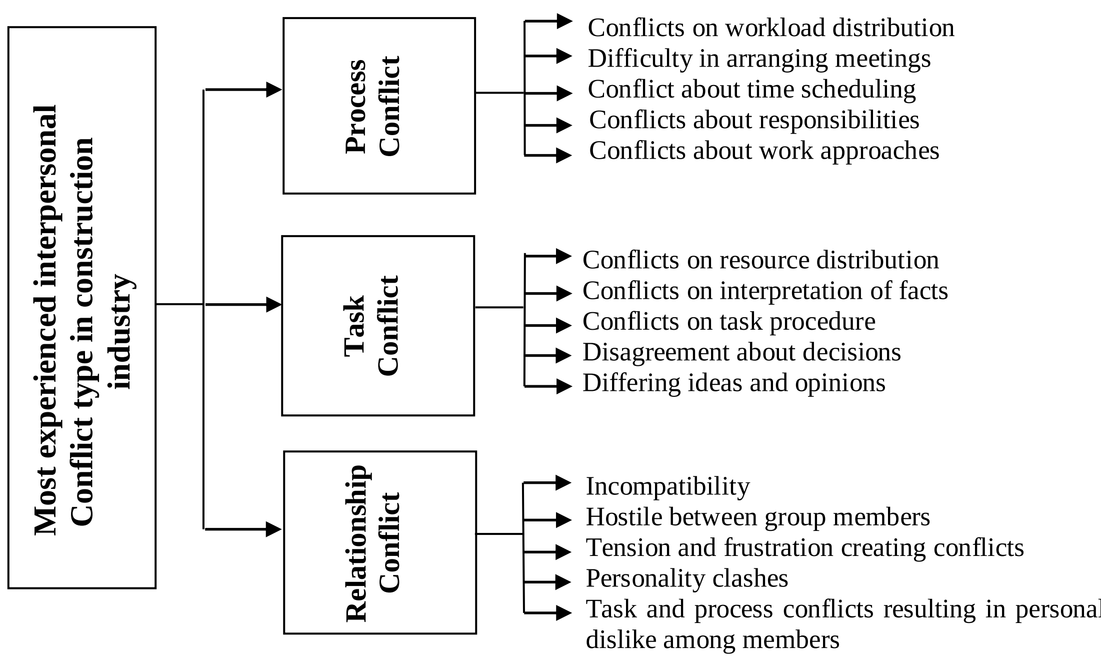

Figure 1: Most Experienced Interpersonal Conflict Type Selection Hierarchy for Construction Industry

2.2 Positive effects of interpersonal conflict

According to Lee (2011), traditional view of conflict is destructive and always gaining negative impact leading to loss of performance. However, many researchers have emphasized benefits of conflicts. During conflict situations, group members become more creative to solve conflicts (Levine *et al*., 1993). Conflicts boost the consideration of new ideas and approaches thus, can generate innovative ideas, which bring in effective changes to activities contributing to organisational success (Baron, 1991). Carnevale and Probst (1998) indicate that conflicts raising environment become more useful than no conflict situations to increase the flexibility of the participant. This is because, such situations increase productive discussion about problems, negotiations, cognitive capacity and relationship strength. Baron (1991) mentions about increased loyalty and cohesiveness among group members, who have confronted with serious problems. Loyalty is a crucial factor in maintaining peaceful environment within an organisation. Therefore, such advantages can have positive effects on performance of group members.

2.3 Negative effects of interpersonal conflict

Every person has their own interests. Therefore, different individuals likely to present interpersonal incompatibilities. This could lead to negative emotions such as anger, anxiety, mistrust and all other bad feelings (Jehn, 1997). These negative emotions are commonly associated with relationship conflicts, which affect negatively to group performance (Jehn and Mannix, 2001). Baron (1991) points out that interpersonal conflicts interfere with communication, which lead to poor cooperation or coordination, diversion of energies from major goals, lead groups to stereotype each other, increase in politics and reduces the organisation’s capacity to compete with others. Due to interpersonal conflict, communication flow will become complex by resulting mistrust, misunderstanding and anxiety. Simons and Peterson (2000) identify that relationship conflict negatively affects group decisions in three ways: restriction of information processing within the group due to waste of time to focus on problems; limit of group member’s cognitive function through increased stress and anxiety levels, and encourage of evil attribution for other members. Thus, mutual hostility can be generated among members due to these reasons.

3. Research Methodology

This research basically attempts to answer two Research Questions (RQ) as RQ1: What are the prioritised different types of interpersonal conflicts in post-contract stage of Sri Lankan construction projects and RQ2: What are the positive and negative influences of such interpersonal conflicts. According to Yin (2009), ‘what’ type of research questions support survey research designs. Accordingly, this research adapted quantitative survey research design by using a structured questionnaire as the data collection technique. Questionnaire consisted of two different sections to collect data and analyse answers for RQs. Section I was designed to answer RQ1 through Analytic Hierarchy Process (AHP) using 9 to 1/9 scale and Section II was designed to answer RQ2 through a 1 to 5 Likert scale [Never (1), Rarely (2), Sometimes (3), Most of the time (4), Always (5)] to analyse data using the ‘mode’ value of the responses. Data were gathered from professionals (Quantity Surveyors, Project Managers, Architects and Civil Engineers) from the construction industry in Sri Lanka, including professionals working for consultants or contractors in projects. The questionnaires were distributed among 39 professionals, adopting purposive sampling and only 30 responded with a response rate of 77%. The main three steps of (1) Pair-wise comparison, (2) Normalise the comparison and (3) Consistency calculation were used for AHP approach (Saaty, 2008). RQ1 was structured as a hierarchy as indicated in Figure 1 to support AHP process. AHP problem hierarchy was constructed so as to priorities and convert individual comparative judgments into ratio scale measurements. Top level of the hierarchy included main types of interpersonal conflicts while, lower level consisted with sub types of interpersonal conflicts.

4. Data Analysis and Research Findings

4.1 RQ1: Prioritised Different Types of Interpersonal Conflicts in Post-Contract stage of Sri Lankan Construction Projects

Initially, the main three types of interpersonal conflicts (relationship-task-process) were prioritised following the three steps of pair-wise comparison, normalisation of comparison and consistency calculation of AHP. The geometric mean of the responses was considered to prepare the pair-wise comparison matrix as shown in Table 1. Comparisons were assessed with the number of scale, which indicated how much one conflict type was more important than the other type of conflict according to the respondent's opinion.

Table 1: Square Matrix of the Pair-Wise Comparison for Main Conflict Types

Main Interpersonal Conflict Type	Relationship	Task	Process
Relationship	1.000	0.370	0.529
Task	2.702	1.000	3.258
Process	1.891	0.307	1.000
Sum	**5.593**	**1.677**	**4.787**

Next, the normalised comparison for main conflict types was done following the calculation of relative weight of each conflict type as presented in Table 2. These relative weights can be used to prioritise the conflict types. According to the normalised comparison for main interpersonal conflicts, task conflicts acquired the highest relative weight of 0.587, proving the task conflicts being the most common interpersonal conflict type in the construction industry. Process conflicts acquired the second highest relative weight of 0.243 and relationship conflict was the third with a relative weight 0.170. According to the normalised comparison, task conflicts are approximately 2 times more experienced than process conflicts and approximately 3 times more experienced than the relationship conflicts. This indicates that task conflicts generate significant impact to the post-contract stage of construction projects in Sri Lanka.

Table 2: Normalized comparison for main conflict types

Main Interpersonal Conflict Type	Relationship	Task	Process	Sum	Relative Weight
Relationship	0.179	0.221	0.110	0.510	**0.170**
Task	0.483	0.596	0.681	1.760	**0.587**
Process	0.338	0.183	0.209	0.730	**0.243**

Sometimes responses data may not be reliable due to inconsistent responses in the questionnaire survey. Therefore, data consistency should be assessed to establish validity of the research findings. Consistency Ratio (CR) was used as a reference index to measure consistency of data. According to (Saary, 1994) CR being 0.10 or below is considered as acceptable. Since CR for prioritised main interpersonal conflicts was 0.066, which was below 0.10, collected data were considered having significant level of consistency and the outcome of the calculations was considered having the validity required. A similar exercise was applied towards calculating the relative weight of sub types of interpersonal conflicts. The prioritised interpersonal conflict types are summarised in Table 3. According to Table 3, each sub type of interpersonal conflict has been ranked following the overall weight calculations.

Results have indicated that task conflicts as the most common type of interpersonal conflicts in the Sri Lankan construction industry. Overall ranking of sub types of interpersonal conflicts indicated that 'conflicts on resource distribution' has obtained the highest weightage in this analysis. Depending on the project complexity and scarcity, resource distribution may be difficult in practice. Yet, proper resource allocation would help to avoid unnecessary conflicts. Second most experienced sub type of conflict was 'conflicts on task procedure'. Those conflicts arise with the proceedings of different tasks in construction projects. Third most experienced sub type of conflict was 'differing ideas and opinions'. Construction is a multi organisational process. Therefore, various parties involve to the proceedings, who carry differing ideas and opinions, which give rise to conflicts. Therefore, task conflicts have been most of the time experienced by professionals in construction projects. Sub types of relationship conflicts such as 'incompatibility', 'personality clashes', and 'hostile between group members' received the least priority among overall ranking.

Table 3: Prioritised Interpersonal Conflict Types

Rank	Interpersonal Conflict Type	Relative Weight	Overall Weight	Overall Rank
1	**Task conflicts**	**0.587**		
1.1	Conflicts on resource distribution	0.329	0.193	1
1.2	Conflicts on task procedure	0.209	0.123	2
1.3	Differing ideas and opinions	0.196	0.115	3
1.4	Disagreement about decisions	0.138	0.081	4
1.5	Conflicts on interpretation of facts	0.128	0.075	5
2	**Process conflicts**	**0.243**		
2.1	Conflict about work approaches	0.300	0.073	6
2.2	Conflict about responsibilities	0.248	0.060	8
2.3	Conflict on workload distribution	0.201	0.049	9
2.4	Conflict about time scheduling	0.143	0.035	10
2.5	Difficulty in arranging meetings	0.108	0.026	13
3	**Relationship conflicts**	**0.170**		
3.1	Task and process conflicts resulting in personal dislike among members	0.417	0.071	7
3.2	Tension and frustration creating conflicts	0.207	0.035	10
3.3	Hostile between group members	0.158	0.027	12
3.4	Personality clashes	0.129	0.022	14
3.5	Incompatibility	0.089	0.015	15

4.2 RQ2: Positive and Negative Influences of Interpersonal Conflicts

9 positive influences and 12 negative influences of interpersonal conflicts, which were identified from literature review were ranked based on a 1 to 5 Likert scale [Never (1), Rarely (2), Sometimes (3), Most of the time (4), Always (5)] by the professionals in construction industry in Sri Lanka. The mode values of the respondents' ranking are indicated in Table 4.

Positive influence of interpersonal conflicts - The most experienced positive influence was that conflicts 'force to take better managerial decisions' with a mode value of 4 (Most of the time) as indicated by 73% of respondents. This demonstrated that managerial decisions were affected in a positive manner by conflicts, where outcome of better managerial decisions could help to improve the project performance. Further, 67% of the respondents indicated that conflicts most of the times (mode value of 4) 'introduce creative solutions to problems'. Accordingly, professionals established that creativity comes with chaos and that such a creativity could drive successful completion of the work. In addition, more than 50% of the respondents pointed out that conflicts most of the times (mode value of 4) ‘increase the ability to give and receive constructive feedback’ and ‘increase understanding among group members’. 63% of the respondents indicated that conflicts sometimes (mode value of 3) ‘improve motivation’ and ‘improve self-esteem’. However, there was no strong consensus among the respondents whether conflicts positively influence on building trust. 10% of respondents stated that it did not happen in the industry, while 33% stated that they had a rare experience on interpersonal conflicts building trust among group members.

Table 4: Mode Values of Positive and Negative Influences of Interpersonal Conflicts

Positive influences of interpersonal conflicts	**Mode**	**%**	**Negative influences of interpersonal conflicts**	**Mode**	**%**
1. Provide creative solutions to problems	**4**	67%	1. Contribute to delays in projects	**4**	60%
2. Force to take better managerial decisions	**4**	73%	2. Build up frustration, resentment, anxiety and tension	**3**	50%
3. Help to re-adjust relationships of parties concerned	**3**	50%	3. Establishment of supportive relationship difficulties	**3**	50%
4. Increase the ability to give and receive constructive feedback	**4**	53%	4. Make barriers in communication	**3**	57%
5. Improve self-esteem	**3**	63%	5. Reduce the individual productivity level	**3**	67%
6. Increase understanding among group members	**4**	50%	6. Divert energies from major goal to others	**3**	63%
7. Improve motivation	**3**	63%	7. Create clashes between members	**3**	57%
8. Contribute to a more interesting work environment	**3**	50%	8. Create incompatibilities among group members to accomplish tasks	**3**	67%
9. Build trust	**2**	33%	9. Create lack of trust	**3**	50%
			10. Make unpleasant working conditions	**3**	63%
			11. Create misunderstanding about tasks	**3**	60%
			12. Reduce the quality of production	**3**	57%

Negative impact of interpersonal conflicts - Research findings unveiled that conflicts ‘contributing to delays in projects’ as the most experienced negative influence with a mode value of 4 (Most of the time) as indicated by 60% of the respondents. All other influences were ranked as sometimes (mode value of 3) influencing negatively. However, more than 60% of the respondents indicated that they sometimes experienced conflicts ‘reducing the individual productivity level’, ‘diverting energies from major goal to others’, ‘creating incompatibilities among group members to accomplish tasks’, ‘making unpleasant working conditions’ and ‘creating misunderstanding about tasks’.

5. Conclusion

This research intended to answer the two research questions; RQ1: What are the prioritised different types of interpersonal conflicts in post-contract stage of Sri Lankan construction projects and RQ2: What are the positive and negative influences of such interpersonal conflicts. In answering the RQ1, AHP calculations have identified that task conflicts are the most experienced type of main interpersonal conflicts in post-contract stage of the construction projects in Sri Lanka, compared to process and relationship types of conflicts. Normalized AHP comparison indicates that task conflicts are approximately 3 times more experienced than relationship conflicts and process conflicts are approximately 2 times more experienced than the relationship conflicts. Further, sub types of task conflicts are having the highest priority among different sub types of main interpersonal conflicts. Accordingly, ‘conflicts on resource distribution’ is the highest experienced sub type of main interpersonal conflicts. In addition, ‘conflicts on task procedure’, ‘differing ideas and opinions’, ‘disagreement about decisions’ and ‘conflicts on interpretation of facts’ received higher priorities among different sub types of main interpersonal conflicts.

In answering RQ2, research findings indicate some positive influences of interpersonal conflicts in construction projects. Construction professionals declared conflicts ‘force to take better managerial decisions’ as the most experienced positive influence. In addition, ‘introduction of creative solutions to problems’ ‘increase of the ability to give and receive constructive feedback’, ‘increase of understanding among group members’, ‘improved motivation’ and ‘improved self-esteem’ are the other top ranked positive influences. Interpersonal conflicts generate not only positive influences, but also negative influences to a construction project. Research findings indicate that most experienced negative influence of conflicts include its contribution to delays in projects. In addition, ‘reducing the individual productivity level’, ‘diversion of energies from major goal to others’, ‘creating incompatibilities among group members to accomplish tasks’, ‘making unpleasant working conditions’ and ‘creating misunderstanding about tasks’ include other major negative influences.

These findings are useful for construction professionals, who work for post-contract stages of construction projects in Sri Lanka for better understanding of possible interpersonal conflict types in projects to benefit from the positive influences and to avoid or minimise the negative influences consciously. This will lead to a better management of human resources in construction projects. Further research suggestions include studying the interpersonal conflict management techniques in construction industry.

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Formation of Photocatalytic, Antibacterial and Self Cleaning TiO_2 Film on Tiles

T. N. S. Palitha
University of Moratuwa, Srilanka
nuwansripalitha@gmail.com

Oshadi D. Palansooriya
University of Moratuwa, Srilanka
oshadidushmantha342@gmail.com

Galhenage A. Sewvandi, PhD
University of Moratuwa, Srilanka
sewvandiga@yahoo.com

Abstract
To ensure healthier environments in food industries, hospitals, swimming pools, pharmacies etc., we must clean the surfaces many times per day. Therefore, introduction of self-cleaning methods will be very useful. This research focused on studying photocatalytic anti-bacterial properties of thin film of TiO_2 synthesized on ceramic tiles by both dip coating and spray coating methods. Antibacterial properties are influenced by a variety of factors, such as crystal structure, surface area, nanoparticle size distribution etc. The TiO_2 exist in three crystalline phases. Anatase is one of the most common and favorable phases used in the manufacturing industries due to its uniqueness of functional performance and favorability to humans and the environment. The anatase structure of TiO_2 was obtained after sintering at 450°C for 45 minutes. The microstructures were characterized by a scanning electron microscope (SEM). The study applied Energy Dispersive Spectrometry (EDS) to determine the chemical constituency of the coating. The study revealed that, dip coating the tile delivered a homogeneous and very thin film on the surface. Coated TiO_2 cannot destroy the bacteria but stops growth of bacteria by a considerable percentage.

Keywords
Photo-catalysis, Dip-coating, Anatase, Energy Dispersive Spectrometry (EDS/EDAX), SEM, E-Coli

1. Introduction

In recent years, growth of opportunistic bacteria in the environment has been responsible for a large number of disease outbreaks in a variety of settings. The demand for environmentally responsible construction and the ever more restrictive environmental requirements derived from legislation have increased the functional requirements of tiles (María *et al.* 2010). Substituting antimicrobial tiles for surfaces support healthier environments. Improving the ability to control and destroy microorganisms, is essential to many organizations and industries such as healthcare, food, water treatment and military (Archana *et al.* 2010).

In particular, to improve the surface cleanability properties the photocatalicity of titanium dioxide (TiO_2) nanoparticles has been used. TiO_2 is a photocatalyst and widely utilized as a self-cleaning and self-disinfecting material for surface coating in many applications. These properties have been applied in removing bacteria and harmful organic materials from water and air, as well as in self-cleaning or self-sterilizing surfaces for places such as medical centers (McCullagh *et al.* 2007). In the field of construction and building materials, it maybe the most widely used (Bondioli *et al.* 2013).

1.1 Objective of the Research

The objective of this research is to develop a TiO_2 coated photocatalyst antibacterial tile, and analyze the physical properties of the film and the antimicrobial activity.

1.2 Titanium Dioxide (TiO_2) Photocatalicity

TiO_2 exists in amorphous and crystalline forms. The amorphous form is photo-catalytically inactive. There are three natural crystalline forms of TiO_2; anatase, rutile and brookite. Anatase and rutile have a tetragonal structure, while the structure of brookite is orthorhombic. Brookite is less common than the former two crystal polymorphs and is far more difficult to obtain (Zeljko *et al,* 2011). Anatase and rutile are photocatalytically active, while brookite has never been tested for photocatalytic activity. Pure anatase is more active as a photocatalyst than rutile, probably because it has more negative potential on the edge of the conductive band, which means higher potential energy of photo generated electrons and also because of a larger number of –OH groups on its surface (Amy *et al,* 1995).

However, TiO_2 activity is influenced by a variety of factors such as crystal structure, surface area, nanoparticle size distribution, porosity and the number and density of hydroxyl groups on the TiO_2 surface (Kwon *et al*, 2008).

2. Experimental Procedure

A nano scale thin TiO_2 film was synthesized on the tile surface in order to not to affect the aesthetic appearance. Two methods were employed to form the thin TiO_2 film on the surfaces of tiles and glass: (1) spray coating; (2) dip coating.

There were, however, difficulties in getting good SEM imagery of TiO_2 films on ceramic tiles. TiO_2 films were, hence developed on Fluorine doped Tin Oxide (FTO) coated glasses as well for improving SEM imagery.

2.1 TiO_2 Solution Preparation and Spray Coating

TiO_2 solution for spray coating was prepared by adding 15 g of TiO_2 powder, 5 ml of surfactant, and 30 ml of acetic acid into a beaker. The mixture was, then stirred in a magnetic stirrer for 20 min, and finally 60 ml of Ethanol was slowly added while stirring continuously for another 20 min.

After preparing the solution, tile samples were coated by using the spray coating method. Finally, all the prepared samples were placed in a furnace and sintered at 450°C for 45 minutes. Hence fabricated films were analyzed using Scanning Electron Microscopy (SEM).

2.2 Ethyl Cellulose Solution Preparation

Ethyl cellulose solution is needed to prepare TiO_2 solution for dip coating tiles (see Section 2.3). 2 g of ethyl cellulose powder and 40 ml of ethanol were put in a bottle and closed properly to prevent vaporization. Contents in the bottle were stirred using magnetic stirrer for 16 hours. Because it did not dissolve properly following alternate formulas were tried:

- 1g of Ethyl cellulose in 40 ml of Ethanol
- 1g of Ethyl cellulose in 40 ml of Acetone

The temperature was, then, slightly increased while stirring. After allowing time for precipitation, the three samples were visually observed. All three appeared same in terms of quantities of precipitates. Therefore, Sample 1 was stirred further, left to precipitate and the solution was taken from the top by using a dropper.

2.3 TiO_2 Solution Preparation and Dip Coating Tiles.

The TiO_2 solution was prepared according to the formula given in Table 1.

Table 1: Material Mixture Formulae

Material	Weight
TiO_2 (P25)	1 g
Ethanol	20 g
Terpineol	4 g
Ethyl Cellulose Solution (Section 2.2)	10 g

All of above were measured and put into the bottle. It was stirred for 4 days at 8 hours per day. Powder particles, however, were not properly dissolved in the solution.

Small tile pieces were prepared by cleaning using ethanol. As described in Sections 2.4 and 2.5, two types of Samples, A and B, were made. They were labeled as given in Figure 1.

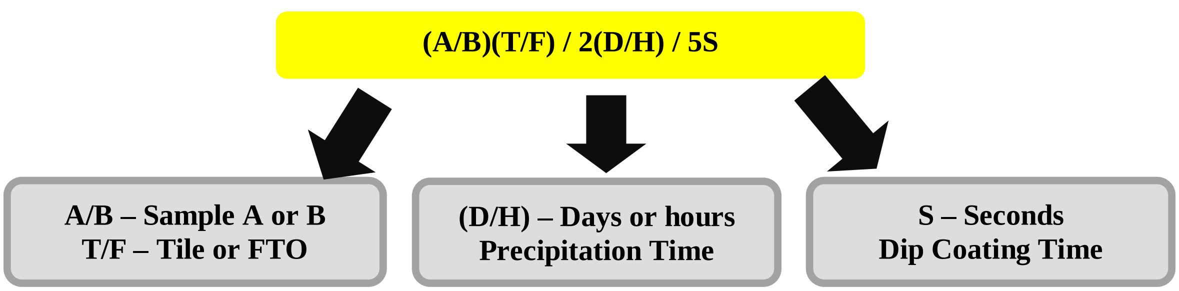


Figure 1: Sample Numbering Label

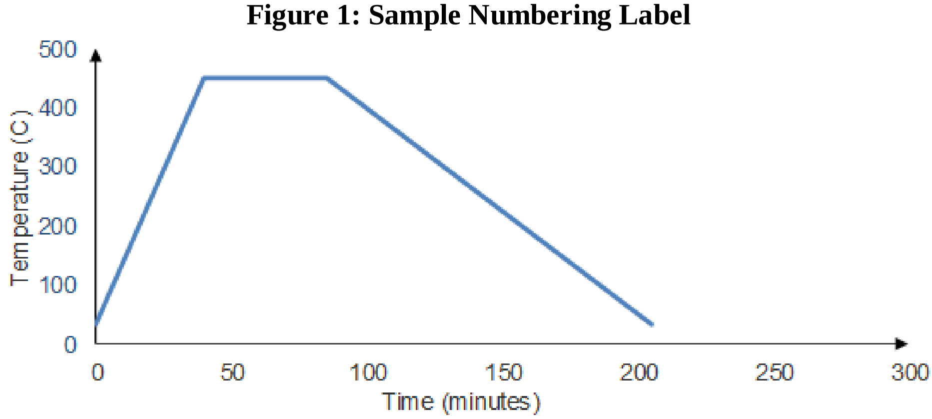


Figure 2: Firing Curve (Time vs Temperature).

Before dip-coating, the solution was put inside the ultrasonic sonicater for 5 minutes. Samples were dip coated inside the ultrasonic sonicater, and sintered in the furnace following the temperature variations given in Figure 2.

2.4 A Samples

When dip coating A samples, the TiO_2 solution was allowed to precipitate over relatively long periods; (a) one hour and (b) one day. Samples were dipped in the supernatant over specified periods as given in Table 2.

Table 2: A Samples TiO_2 Supernatant Preparation Condition and Dip Coating Time

Dipping Time / Supernatant Condition	5 seconds	10 seconds	20 seconds
After one hour precipitation	AT/1H/5S	AT/1H/10S	AT/1H/20S
After two days precipitation	AT/2D/5S	AT/2D/10S	AT/2D/20S

2.5 B Samples

When dip coating B samples, the TiO_2 solution was not allowed to precipitate over relatively long periods. All dipping happened with precipitation times maximum 2 minutes as given in Table 3. Samples were dipped in the supernatant over very brief period of less than 5 seconds.

Table 3: B Samples Dip Coating Times of Samples

Sample	Precipitation Time
BT/00S	0.5 ~ seconds
BT/15S	15 seconds
BF/60S	60 seconds
BT/120S	120 seconds

2.6 Application of TiO_2 Layer on FTO Glass and Tile

One piece of Fluorine doped Tin Oxide (FTO) coated glasses was used to prepare an additional sample to improve SEM imagery. The FTO glass piece was dip coated by using the solution given in Table 1. Again, the mixture was stirred for 15 minutes and left to precipitate.

2.7 Drying and Sintering of Samples

Table 3 presents dip coating times for all samples; tile pieces as well as the glass.

All the samples were put inside the small closed vessel, dried by air for 15 minutes and dried by oven at 50 °C for 15 minutes. To enable placing the samples in oven such that impurities will not contaminate the surfaces, they were placed in a small container made of tiles. Then samples were sintered in the furnace following the temperature variations given in Figure 2. Samples were observed by the SEM.

2.8 Culture Medium Preparation and E.coli Growth

27 g of HiCrome Coliform Agar w/SLS (supplied by HiMedia[1]) was suspended in 1000 ml distilled water. The agar was heated up to boiling to dissolve the medium completely. Then the agar medium was sterilized by autoclaving at 15 psi pressure (121°C) for 15 minutes. As a precaution manufacturer advised to add 5 mg/l novobiocin before autoclaving the medium, when a high number of gram positive accompanying bacteria are expected.

After cooling the prepared culture medium to 45-50°C, 10 ml of medium was mixed well and poured into petri plate. Then 1 ml of E.coli solution was distributed on the dried out culture medium. E.coli solution

[1] HiMedia Laboratories, Mumbai, India, http://www.himedialabs.com

was extracted from a well grown E.coli sample, and ten times diluted before application. Then E.coli distributed samples were placed in an incubator at 44°C. To identify the shape, bacteria density and distribution of E.coli growth on the culture medium, Optical microscope images were taken (see Figure 4).

2.9 Investigation of Anti-Bacterial Activity of Synthesized Solution

To investigate the antibacterial activity in the solution given in Table 1, two methods were used.

1) Prepared bacteria samples placed on the coated surface (see Figure 5).
2) Prepared bacteria samples placed inside the solution (see Figure 6).

1 cm^2 bacteria samples were cut and number of bacteria were counted by using optical microscopic images. Then all samples were kept under sunlight and after one hour, number of bacteria were again counted. The image of immersed samples were not clear. But images of samples which were placed on the coated surfaces were clear. Then they were kept under sunlight for another hour and again counted.

Figure 5: Bacteria Samples Placed on the Coated Surface

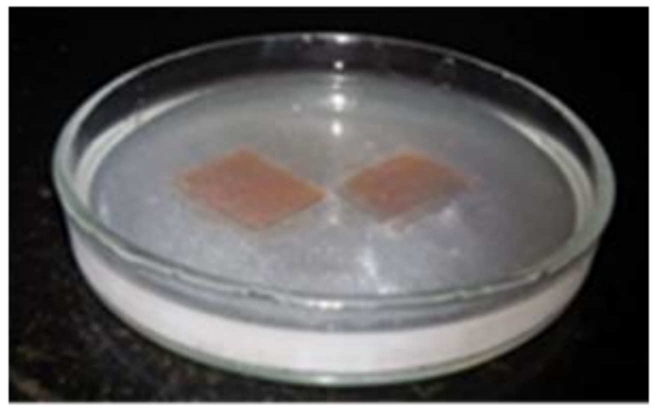


Figure 6: Bacteria Sample Immersed in the Solution

3. Results and Discussion

3.1 XRD Analysis of TiO_2

X ray diffraction pattern (XRD) of the general purpose regent TiO_2 sample is shown in the Figure 7. In XRD patterns, powder particles show strong diffraction peaks with crystalline nature. The 2θ peaks lying at 2θ = 25.4 (101), 37.893 (004), 48.172 (200), 53.979 (105), 62.769 (204). When these peaks are compared with standard spectrum peaks, this sample includes TiO_2 anatase phase (Thamaphat). Small peaks correspond to the impurities present in the TiO_2 powder sample we used.

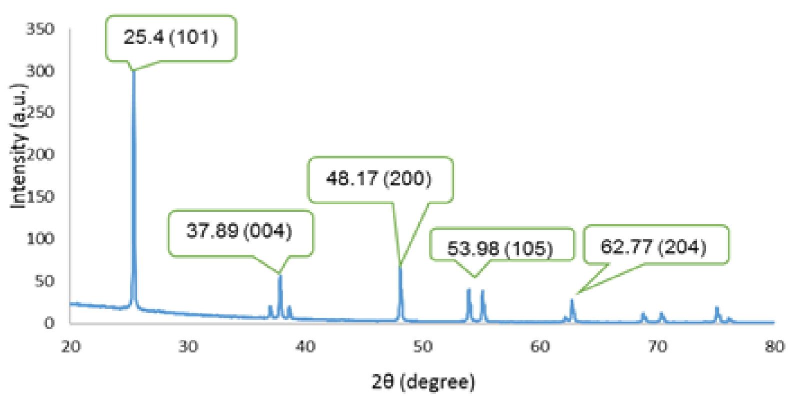


Figure 7: XRD patterns of TiO_2 sample

The preferred orientation is corresponding to the TiO_2 anatase phase. Some peaks are close to TiO_2 rutile phase and some of the small peaks which cannot be indexed can be attributed to the impurities contaminated with the TiO_2 powder sample.

3.2 SEM Analysis of TiO_2 Spray Coated Layer

Very simple equipment that was used for spray coating, was very easy to handle. There were, however, some disadvantages:

- irregularities of coated surface
- coating not being durable
- layer thickness being high causing surface to become white and

Solution properties and coating mechanism, hence, need to be further developed.

Figure 8 shows SEM micrograph of the TiO_2 coating prepared by the spray coating method and sintered at 450 °C for 45 minutes. Nano size TiO_2 particles were identified in the coating by observing the SEM image of TiO_2 coating. There were some irregularities of surface coating, and durability of the coating was low. EDS analysis was, hence, not carried out.

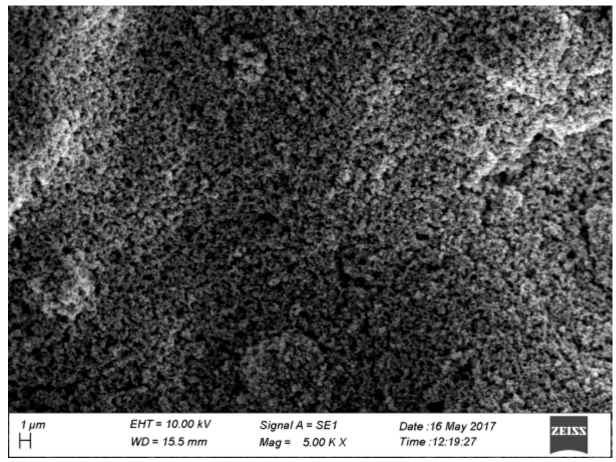
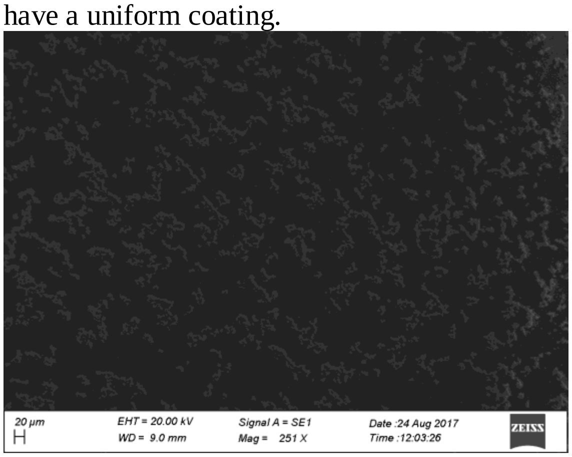


Figure 8: SEM Image of TiO_2 Spray Coated Tile Surface

A clean tile sample was used to observe the pores by using SEM. But ceramic tiles are non-conductive. A result of that was the very dark image of the surface. Optical microscope was, therefore, used to observe the surface quality. Optical microscope revealed that there were lot of pores on the surface.

3.3 A samples: SEM and EDS Analysis of TiO_2 Layer

There was no TiO_2 coating observed on first five samples. A small percentage of area of TiO_2 was observed on the sample AT/1H/10S [TiO_2 dip coated tile surface (Coating time 10 seconds)] and sample AT/1H/20S [TiO_2 dip coated tile surface (Coating time 20 seconds) (see Figure 9)]. The latter did not have a uniform coating.



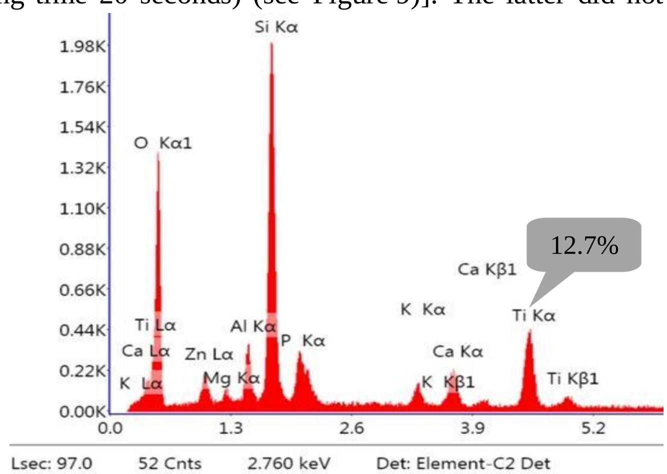


Figure 9: SEM Image of Sample AT/1H/20S

Figure 10: EDS Pattern of Sample AT/1H/20S

Energy Dispersive Spectrometry (EDS) analysis of the dip coated TiO_2 film is given in Figure 10.

There are so many reasons for above results. Ethyl cellulose which we used is a commercial grade sample. Therefore we do not know whether it is pure Ethyl cellulose or not. Ethyl cellulose was not dissolved completely in ethanol and also TiO_2 nano particles were not dissolved in the coating. Having experienced the above results B samples, where the TiO_2 solution was not allowed to precipitate, were tried.

3.4 B samples: SEM and EDS Analysis of TiO_2 Layer

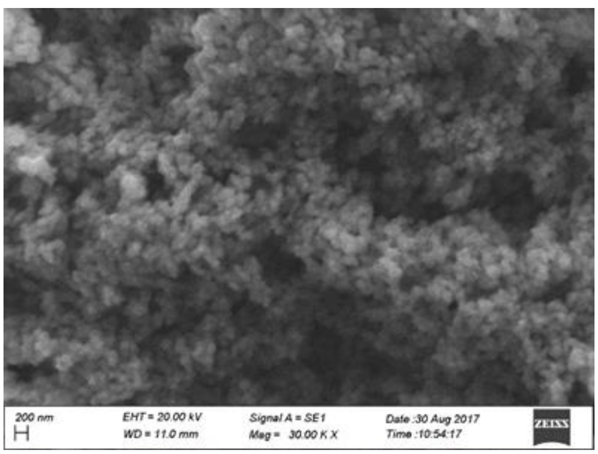


Figure 11: SEM Image of Sample BT/00S

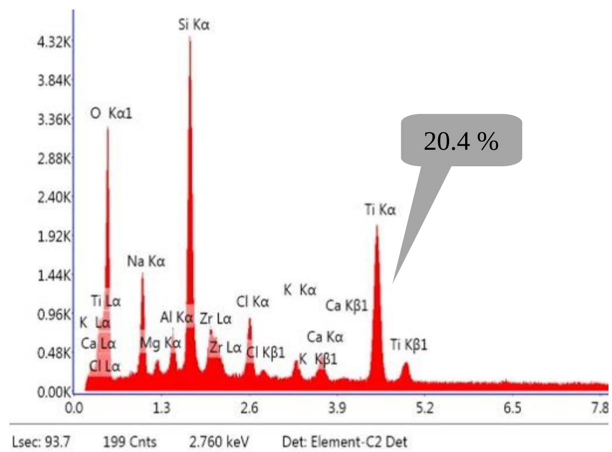


Figure 12: EDS Pattern of Sample BT/00S

According to the SEM analysis only sample BT/00S (Figure 11) has complete coating layer and all of other samples have no regular layers. According to that we can deduce that there are some TiO_2 particles left in the solution when stirring but all of those particles did precipitate very quickly. That means particles are just mixed, not dissolved in solution.

Figure 12 shows EDS graph of the TiO_2 coating prepared by the dip coating method sintered according to firing curve given in Figure 2. According to the EDS analysis highest peak index is Silicon. Silicon is a material which is in the tile, but not in coating. When considering other peaks they show Oxygen and Titanium in considerable percentages. EDS graph further indicated presence of other materials like Sodium, Calcium, Aluminum, Potassium, Magnesium etc. They can be considered as materials from impurities on the tile surface.

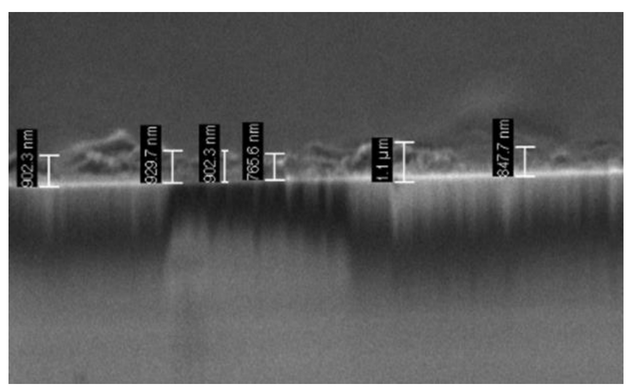


Figure 13: SEM image of BT/00S Sample film thickness

Figure 13 shows the SEM image of the thickness and homogeny of the layer. TiO_2 thickness obtained on the tiles by the dip coating method is around 900 nm. Micro TiO_2 particles were identified in the coating by observing the SEM image of TiO_2 coating. That means TiO_2 particles are agglomerated. So, there were some irregularity of surface coating and durability of the coating is low. The performance of the film is highly dependent on the homogeny and the thickness of the TiO_2 layer.

In the dip coating method material wastage is high and there were some irregularities of coated surface. So solution properties and coating mechanism are in need of development.

3.5 Investigation of Anti-Bacterial Activity of Synthesized Solution

Optical microscope images of immersed samples were not clear, because TiO_2 fine particles were deposited on the bacteria sample. The bacteria samples which were placed on the coated surface were very clear as before. There was, however, no significant difference of number of bacteria that had grown. The reason, apparently, was bacteria growth is inside the agar media, and not the surface of the tile. Therefore, bacteria were not in contact with the synthesised coating. It was, therefore, observed that, coated TiO_2 coating cannot affect the bacteria growth inside the agar media.

4. Conclusions

Properties of the TiO_2 coating mainly depended on the mechanism used to coat the surface.

- Spray coating the tile surface by the apparatus used was not successful, because the coating was not homogeneous and came off very easily.

- Dip coating the tile delivered a homogeneous and very thin film on the surface.

- However, A samples where the TiO_2 solution was allowed to precipitate did not yield a uniform TiO_2 coating

- Only the B sample that was made with no time allowed for TiO_2 to precipitate, yielded a complete TiO_2 coating layer.

The above is because TiO_2 particles did not dissolve properly in the Ethanol or particles were agglomerate together.

It was, observed that, coated TiO_2 cannot destroy the bacteria but it stops the growth of bacteria by a considerable percentage.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan

Salman Azhar, Kamal Ahmed, Amna Salman
McWhorter School of Building Science, Auburn University, Auburn, Alabama, USA

Abstract

Commercial and residential sector buildings consume up to 40% of world's energy production. It is estimated that the developing countries will consume up to 65% of world's energy by 2040. Pakistan is one of the developing countries which is facing a huge gap in supply and demand of electricity. Residential sector is the largest consumer of electricity in Pakistan which currently consumes 47% of total electricity production. The process of energy consumption can be made more efficient by using an energy efficient home design. In Pakistan, the lack of basic understanding of a sustainable home and a higher upfront cost of sustainable design are two biggest barriers hindering the implementation of green solutions. The purpose of this research study was to develop typical single family detached home designs for Pakistan and apply different Energy Efficiency Measures (EEMs) to study their impact on electricity consumption. For home modeling, data related to climatic conditions, home designs, construction materials and electricity rates was collected from Lahore, Pakistan. eQUEST® (Quick Energy Simulation Tool) was used for baseline modeling and running energy simulations. Four different home designs within size range of 75 m^2 to 475 m^2 were modeled. A baseline design was first developed in accordance with typically used construction practices in Pakistan. In energy efficiency designs, several energy efficiency measures were separately applied to baseline design to see their impact on electricity consumption. Results showed that by applying these energy efficiency measures, there is a potential of reducing electricity costs by up to 26%. It was observed that lighting-power density, roof color, roof insulation and wall insulation result in most reduction in electricity consumption. It is suggested that government, housing authorities, designers, contractors and home owners help in promoting these energy efficiency measures to achieve maximum energy savings in the residential sector.

Keywords

Energy efficient design, Residential construction, Green home, Energy simulations

1. Introduction

Start The International Energy Agency (IEA) estimated that residential, commercial and public buildings account for up to 40% of the world's energy consumption (Woody, 2013). These numbers are even higher for developing countries and recent estimates suggest that developing countries may consume up to 65% of the world's energy by 2040 (Woody, 2013). Pakistan, a developing country in South Asia, is facing a huge gap in supply and demand of electricity. Energy crisis is one of the top three issues that are significantly impacting the lives of people in Pakistan (PewGlobal, 2017). In the last decade, Pakistan has been badly affected by the shortfall in energy because of economic growth and better living standards. The electric power deficit had crossed the level of 7,000 MW/day at many points during the years 2011 through 2016 (Aftab, 2014). The persistent shortage of electricity in the country has adversely affected the national economy. Industrial production has been severely hit; and also triggered social unrest which sometimes turns violent thus, thereby creating law and order problems in many urban centers in the country (Aftab, 2014). According to recent studies, the power shortages have resulted in an annual loss of about 2% of GDP, and total industrial output loss in the range of 12%-37% (Siddiqui, 2011).

Energy efficiency in the built environment is vital to achieving climate energy, and development objectives in emerging economies. There is increased recognition that the cost of reducing energy consumption is much lower than the cost of generating new energy (Managan *et al.*, 2011). Energy-efficient buildings bring many benefits to their owners, their occupants, and the society as a whole. Owners benefit from lower operating costs due to reduced energy usage, and occupants benefit from greater comfort through better insulation and lighting. Benefits to society include reducing greenhouse gas emissions, increased energy security, and improving air quality through lower consumption of electricity, the majority of which comes from burning fossil fuels (Managan *et al.*, 2011).

In Pakistan, there is a need to develop design and construction standards and practices for energy efficient buildings and homes. Moreover, the life cycle cost analysis of different energy efficient designs is needed so that the owners have a better idea why they should incorporate these energy efficient designs even though these improvements typically result in higher initial investment costs. A green building is designed to use less energy and water and to reduce the life-cycle environmental impacts of the materials used. This is achieved through better site planning, design, material selection, construction, operation maintenance, removal, and possible reuse (Azad and Akbar, 2015). There are several modeling and energy simulation tools available for designing the buildings more efficiently. These tools enable us to incorporate energy efficiency measures in the building design stage and evaluate their impact on building performance. One of the biggest recent developments for the design and construction industry is Building Information Modeling (BIM). BIM is an intelligent 3D model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure (Azhar, 2011). BIM is a platform that can provide a comprehensive and interactive assembly of the components in a building to create an interactive energy model. This virtual model becomes more and more closer to the real world building as more information is added to BIM for each individual part of the building. Using BIM one can model the similar conditions of the actual buildings and run energy simulations based on actual design, construction and climatic data (Azhar, 2011).

The aim of this research study is to use Building Information Modeling (BIM) based energy simulations to develop energy efficient designs for single family detached homes in Pakistan. The research tested various energy efficiency improvement measures and identified the ones that result in best performance. This research is limited to design development of single family detached homes in Pakistan. Size of these homes ranges from 75 m2 to 475 m2. The weather conditions considered for this research are of hot climate areas, since the major portion of population in Pakistan is in the hot climate region. Moreover, the focus city for this research is Lahore (31° 32′ 59″ N, 74° 20′ 37″ E) which is the second largest city of Pakistan and lies in hot climatic region where summer season dictates the type of home design. Summer spans from mid-April to mid-September. The hottest month is June, where average highs routinely exceed 40 °C (104 °F). The coldest month is January where average temperature is in the range of 6-10°C (43-50°F).

2. Literature Review

Worldwide, individuals and organizations have responded to the increased demand for energy efficient buildings. The terms energy-efficient, green and high performance buildings are typically used interchangeably. According to the Office of Energy Efficiency and Renewable Energy (EERE) of the US Department of Energy, a high performance building "…uses whole-building design to achieve energy, economic, and environmental performance that is substantially better than standard practice". The creation of high performance buildings is best addressed through effective building design, which integrates three general approaches: (1) designing a building envelope that is highly resistant to conductive, convective, and radiant heat transfer; (2) fully implementing passive design; and (3) employing renewable energy resources. Passive design employs such strategies as building geometry, orientation, window design, and mass to condition the structure using natural and climatologic features such as the site's solar insolation, prevailing winds, local topography, microclimate, and landscaping (Kibert, 2012).

In Pakistan, the residential sector is the largest consumer of electricity, consuming approximately 45.6% of total electricity supply, followed by Industrial (28.4%), Agriculture (11.8%), Commercial buildings (7.4%), Public buildings (6.2%), and Street lights (0.6%) (Nasir *et al*., 2008). These numbers indicate that buildings and homes together consume approximately 60% of total electricity produced in Pakistan. The total capacity of electric power generation in Pakistan is approximately 19,681 MW/day, whereas the peak demand is approximately 26,520 MW/day (Nasir *et al*., 2008). Even a 10% electricity savings in buildings and homes could result in an overall savings of approximately 1,200-1,500 MW/day which is equivalent to a daily power generation of 3-4 medium size coal power plants (Kibert, 2012).

The majority of urban homes in Pakistan are constructed using masonry walls and reinforced concrete roof, whereas reinforced concrete frame with masonry partition walls is typical in public and commercial buildings. In most cases, the builders construct homes and buildings without any thermal insulation for higher return. A significant amount of energy is wasted due to the heat gain/loss through non-insulated walls and roofs. On average, 36% electricity is utilized for space heating/cooling, 35% for lighting, and 29% for home/office appliances in Pakistan (Masood and Shah, 2012). By constructing energy-efficient and passive buildings, maximizing daylighting, and using high-efficiency appliances, significant savings can be achieved.

In Pakistan, there have been some attempts to promote energy efficient design. For example, the National Energy Conservation Center (ENERCON) developed the "Building Energy Code of Pakistan" in 1990. This code was mostly based on American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) standards. The code provided minimum performance standards for building windows and openings, heating, ventilating and air conditioning (HVAC) equipment, and lighting. The Building Energy Code was non-mandatory and over the years did not result in any significant improvements in local design practices. In 2011, ENERCON and Pakistan Engineering Council (PEC) thoroughly revised this code and made it an integral part of the Pakistan Building Code of 1986 (i.e. Energy Provisions-2011). These Energy Provisions shall apply to buildings and building clusters that have a total connected load of 100 kW or greater, or a contract demand of 125 kVA, or a conditioned area of 900 m2 or unconditioned buildings of covered area of 1,200 m2 or more. At this point, no published data are available for evaluating the usefulness and applicability of these energy provisions. Furthermore, it is important to realize that most buildings in the country are too small to be covered by this code, but use much energy because of their numbers (Masood and Shah, 2012).

3. Research Design and Methodology

The research design is outlined in Figure 1 which is divided into three phases. In the first phase, modeling of baseline homes was completed using design and construction data from Lahore, Pakistan. It was followed by energy simulations and applying energy efficiency measures to compare the results with the baseline design. In the last phase, the cost and feasibility of energy-efficient design features was evaluated and final recommendations are made.

Four typical home designs; Home A, B, C and D were selected from Lahore, Pakistan (Table 1). The floor plans of these homes are shown in Figure 2. These floor plans comply with the locally enforced residential by-laws. Typical construction of the home was composed of brick masonry and RCC slab.

Figure 1. Research design

Table 1: Selected home sizes for the research study

Home	Local Designation	No. of Floors	Covered Area	
			m^2	ft^2
Home A	5 Marla	1	75	815
Home B	10 Marla	1	125	1325
Home C	1 Kanal	1	230	2500
Home D	2 Kanal	1	475	5100

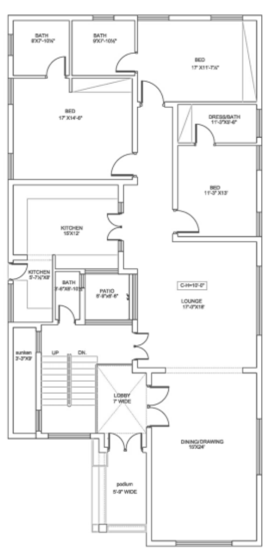
As described previously, modeling and energy simulations were carried out in Revit® and eQUEST®. In eQUEST®, the modeling is performed through wizards called "Schematic Design Wizard" and "Design Development Wizard". The baseline modeling process followed the following major steps:

1. First the general information about the project was added. It included project name, type and location. Weather data file is added into the project via a .BIN file which stores the local yearly weather data. Home's area, floors and type of air conditioning equipment were also selected in this step.
2. Next, the footprint of the home was defined. This was achieved by importing a Revit® file and then defining custom areas and zones. Floor height as well as building orientation were defined. Moreover, the air-conditioned and non-air-conditioned zones were defined.
3. In this step, properties of building envelope were defined. It included roof details, exterior wall details and ground floor construction details. The roof and wall construction allowed us to select appropriate type of materials involved in the construction of the home. Custom roof and wall sections can be made to depict the actual design as accurately as possible. In this study, roof was composed of 15 cm (6 inches) thick RCC slab with sand and tile insulation. Walls were made up of bricks with plaster layer on both sides.
4. After the creation of the building model, exterior doors and windows were added. The doors and windows size and type were selected as per local design and placement was made on each wall according to the plan. The window-wall ratio of walls on each side were also defined.
5. Next, the home's operation schedule was defined. In this step, it was assumed that home will be unoccupied for 6-8 hours during the day. However, that is not the case in actual conditions. This was only done to limit the operational hours of the HVAC system because in local homes air-conditioning is mostly used during the nights and in day time its use is limited.
6. After that, various activity areas were defined (e.g. living areas, bedrooms, etc.) followed by allocation of non-HVAC and HVAC loads to these areas. For this study, HVAC split system was used because this is the common system used in residential homes in Pakistan. DX Coils were selected which represent split system. The air path was assumed to be direct rather than duct system since a separate split system is used in each zone. The cooling temperature for summer was selected as 26 °C (78 °F). The Seasonal Energy Efficiency Ratio (SEER) of 6 was selected. The number of

split AC systems assumed for Home A, B, C and D were one, two, three and five respectively. Each system had cooling capacity of 1 Ton (12,000 Btu/h). It was assumed that ACs in bedrooms operate 8 hours a day and remaining ACs run 4 hours a day.

7. After the modeling process, energy simulations were run on the baseline design. These simulations gave the results of total monthly and yearly energy consumption of the homes in kWh. The results were validated against actual electricity bills and minor refinements were made.
8. After performing energy simulations for the base designs, the following Energy Efficiency Measures (EEMs) were added into the base models one by one: (a) Roof and wall insulation; (b) Change of roof color; (c) Windows size reduction; (d) Energy efficient glass for windows; (e) Windows glass color; (f) Windows shading; and (g) Adjustments in lighting power density.
9. After reviewing the simulation results and incorporating EEMs, comparison results were obtained to analyze the effect of each EEM. In this step different, the best EEMs were shortlisted.
10. Based on the energy simulations, a set of recommendations is prepared for the designers and constructors as well as various government agencies.

Home A **Home B**



Home C **Home D**

Figure 2. Floor Plans of Selected Home Designs

4. Results and Discussion

The energy simulation results indicated that the following four energy efficiency measures; Lighting Power (LED usage), White Paint on Roof, Roof Insulation and Wall Insulation had a significant impact on annual electricity consumption. Table 2 shows the percentage reduction in annual electricity consumption for first four energy efficiency designs when compared with the baseline designs. The other four measures; Windows Size Reduction, Double Glazed Tinted Glass, Single Glazed Bronze Tint and Windows Overhang had negligible impact on annual electricity consumption.

Table 2: Reduction in Annual Electricity Consumption compared to Baseline Designs

Energy Efficiency Measure	Home A	Home B	Home C	Home D
Lighting Power (LED usage)	-12%	-8%	-11%	-17%
White Paint on Roof	-10%	-6%	-7%	-8%
Roof Insulation	-5%	-3%	-4%	-3%
Exterior Wall Insulation	-0.3%	-1.8%	-1.4%	-1.1%

The results from energy simulations indicated that replacing the CFLs with LEDs has the biggest impact on reduction in electricity consumption. This was due to reduced area lighting loads while the cooling loads remained similar as baseline designs. The area lighting loads decreased significantly when CFLs were replaced with LEDs. The annual reduction in electricity consumption ranged from 56% to 66%. A previous case study has shown that replacing CFLs with LEDs reduces electricity usage by 54%. The LEDs had higher initial cost but the lifetime money savings were twice as many as CFLs. This was because of a longer lifespan of LEDs. As the LED technology is improving costs are decreasing and LEDs are becoming more efficient (Soni and Devendra, 2008).

For reduction in cooling loads, the most effective energy efficiency measure was found to be application of white paint on roof. Table 3 shows percentage reduction in cooling loads using white paint, roof insulation and wall insulation. These results comply with a case study conducted in Islamabad, Pakistan (UNHabitat, 2010). This study measured inside temperature of a house with no roof treatment and compared it with inside temperature of house with white paint/lime wash on roof. This process was carried out for a month. Results showed a temperature reduction of 4.1°C (8 °F) with the application of white paint on roof (UNHabitat, 2010). A lower inside temperature meant that cooling load will be decreased to achieve the desired cooling temperature. The cooling loads were also decreased for all homes with the introduction of roof insulation. These results comply with aforementioned case study conducted in Islamabad, Pakistan. This study measured inside temperature of a house with no roof treatment and compared it with inside temperature of house with 2” thick *Diamond Jumbolon Insulation™* on roof. This process was also carried out for a month. Results showed a temperature reduction of 4.7°C (9 °F) with the introduction of insulation on roof (UNHabitat, 2010).

Table 3: Annual Cooling Loads for Baseline and Energy Efficient Designs

Home	Cooling Loads (kWh)						
	Baseline	White Paint on Roof	% Reduction	Roof Insulation	% Reduction	Wall Insulation	% Reduction
Home A	2511	2096	17%	2292	9%	2498	1%
Home B	4484	4009	11%	4288	4%	4344	3%
Home C	5460	4760	13%	5120	6%	5350	2%
Home D	9830	8190	17%	9160	7%	9510	3%

The last four measures; Windows Size Reduction, Double Glazed Tinted Glass, Single Glazed Bronze Tint and Windows Overhang had negligible impact on the annual electricity consumption. The windows size was reduced by 20%. The Window-Wall Ratio (WWR) in the baseline designs was 15%, while in energy efficiency designs it was 10%. This was in accordance to a previous research study which showed that changing WWR from 15% to 10% resulted in 1.5% reduction in annual energy consumption (Kim et al., 2016). The double glazed window glass had no significant impact on energy consumption either. These results complied with a previous research conducted for a house design in Miami, Florida (Hot Climate City) which indicated that, “In hot climates, window insulation has virtually no influence in home heating and cooling energy consumption” and there will be no energy benefit provided by multiple glazing of windows (Kim et al., 2016). This is also the case with single glazed tinted glass which did not provide substantial benefits. Tinted glass may be used to control solar heat gain but typically provides limited insulation benefit (AWS, 2017). The last measure was the introduction of window overhang which did not provide any significant savings in electricity consumption. The overhang provided in this research study was 45 cm (1.5 ft) wide over an 240x180 cm (8x6 ft) window. A previous study conducted for a house design in Calcutta, India showed results of 0.5m (1.6 ft) wide window overhang over a 320x200 cm (10.5 x 6.5 ft) window. The results showed an average reduction of 2% in energy consumption. Although, this reduction became significant when overhang size was increased up to 1.5m (5 ft) (Shaik, 2016). Table 4 summarizes the total potential percentage reduction in annual electricity consumption if all of these measures are applied simultaneously on baseline designs. The results show that on average, electricity consumption can be reduced by up to 26%.

Table 4: Total Potential Reduction in Electricity Consumption

Energy Efficiency Measure	Home A	Home B	Home C	Home D
Lighting Power (LED usage)	-12%	-8%	-11%	-17%
White Paint on Roof	-10%	-6%	-7%	-8%
Roof Insulation	-5%	-3%	-4%	-3%
Exterior Wall Insulation	-0.3%	-1.8%	-1.4%	-1.1%
Windows Size Reduction	-0.0%	-0.1%	-0.2%	-0.2%
Double Glazed Tinted Glass	-0.0%	-0.4%	-0.5%	-0.3%
Single Glazed Bronze Tint	-0.0%	-0.3%	-0.4%	-0.3%
Windows Overhang	-0.0%	-0.2%	-0.1%	-0.4%
TOTAL	-28.1%	-19.5%	-24.8%	-30.3%

5. Conclusions and Recommendations

This paper presented development, testing and life cycle cost analysis of energy efficient designs for typical single family detached homes in Pakistan. Residential sector in Pakistan consumes approximately 47% of produced electricity. Electricity must be used more efficiently in order to reduce its consumption. This can be achieved by applying energy efficiency measures in design and construction phase of the homes. Results of this study shows that there is a potential of reducing electricity consumption by up to 26% using various energy efficiency measures. The energy simulation results showed that replacing Incandescent and CFL light fixtures with the LED fixtures had the biggest impact on electricity and money savings. It is very important to incorporate LEDs in residential sector as LED technology is improving and its cost is also decreasing. Secondly, roof treatment in the form of application of white paint on roof substantially decreased the electricity consumption with relatively lower initial investment. Moreover, thermal insulation on roof and external walls resulted in lower electricity consumption although their initial investment is relatively higher. The results of the Life Cycle Cost Analysis (LCCA) showed that combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years of home’s service life. It is strongly recommended that various energy efficiency measures are implemented in residential designs in Pakistan. Implementation process will require continuous effort from government, housing authorities, designers, contractors and home owners. Government officials should help organize workshops that promote energy efficient practices. Another way to promote this knowledge is through social and print media. Social media can significantly help expanding this message across wider range of public. It is the responsibility of local housing authorities in Pakistan to make sure these measures are implemented. It can be achieved by including these energy efficiency measures in residential by-laws and codes. Some of the energy efficiency measures like LED usage and White Paint on roof can be made mandatory in house construction as they have lower initial cost and biggest savings. Moreover, home owners and builders should consider these energy efficiency measures in the planning phase because they will save their money in the long run and also save country's electricity production. Ultimately, it will result in surplus electricity rather than a shortfall and overall living standards will be improved.

6. Acknowledgment

This research study is funded by the US Department of State and the Higher Education Commission of Pakistan (HEC) under the joint Pakistan-U.S. Science and Technology Cooperation Program (Phase 6).

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The Journey of Exploring 'Construction as Biological Cells' for Improving Construction Quality: Aritculating the research paradigm

Vasantha Abeysekera
School of Civil Engineering and Surveying, Faculty of Health, Engineering and Surveying
University of Southern Queensland, Queensland, Australia; figur.abeysekera@usq.edu.au

Mayur Shelke
University of Southern Queensland, Brisbane, Queensland, Australia
Quality Coordinator, Tier 1 Construction Company; mgshelke@hotmail.com

Abstract
Quality problems in construction is commonplace including defects. This study reports the journey to date of using a novel approach to explore solutions with *construction as biological-cells* simile. Ontological and epistemological issues regarding this approach is discussed arguing for postmodernism for comprehending *reality,* creating *knowledge* by applying logic (reason) to questions constantly in order to develop justified beliefs. *Intuitive* and *reflective inferences* have been made throughout when using *simile* as when synthesising the *Readiness-Growth-Rest* model and associated concepts published earlier explaining the approach using the simile *methodology as spiral* under the umbrella of the simile cum metaphorical approach established for such studies by the authors. The study advocates the use of this method for exploring solutions to perennial problems explaining the challenges with the simile *methodology as spiral* and how it could be used for advancing the notion of *theory as scientific practice.*

Keywords: cell, metaphorical analysis, production management, quality management, simile

1. The Context
Construction is plagued with defects almost cancerous in nature without a cure in sight. In this regard, the notion of cell division in biological cells with a remarkably low defect rate has inspired an investigation into how such is possible. Could those in construction benefit by understanding this process, and in some way, replicate it …? Others have benefitted learning from nature (Benyus, 2002; El-Zeiny, 2012; Gruber et al., 2011; Martinez-Boubeta et al., 2013) so would this be possible in construction particularly when managing quality as defect free? A seemingly impossible and irrational task given that construction is quite different to biological cells. However, the promise of a new line of inquiry labelled as the *simile cum metaphor* approach provides hope as evidenced by Abeysekera's (1997) study on Brickwork as Chaos, and Monetary Retention as Cash Cow, Steroid, Beast, etc. in Abeysekera's (2008) study; and more recently Abeysekera's and Shelke's (2013, 2015a, 2015b, 2017, 2018) study of *construction as biological cells* provide inspiration and confidence in the pursuit of finding a fresh approach for improving process quality..

Notably, despite the collective wisdom on quality management through ISO 9000 and the like, there is still a need to improve construction quality judging by the spate of defective work in construction. Various studies have estimated rework costs are in the range of 10% to 20% of the project cost (Josephson, Larsson, & Li, 2002; Love & Li, 2000; Love, Teo, & Morrison, 2017; Rosenfeld, 2009) which of course may vary from country to country and form project to project. These are the direct cost of quality, and can only increase further if the intangible cost of poor quality is also considered. Accordingly, as hinted above, it would be useful to learn from nature as to whether it would be possible to improve the status-quo. It is in this regard that the *simile cum metaphorical* approach provides the nutrients to pursue a new line of investigation to develop new insights on how to improve practice. As such, this paper examines the journey thus far with the simile *construction as biological cells* hoping to improve current practices on quality management with a special focus on minimising defects.

2. Aims and Objectives

As noted above, the objective of this paper is to describe the journey thus far exploring the simile *construction as biological cells* – it's birth, the challenges, the research paradigm, and future with the aim of developing a management framework for the elimination (or reduction) of defects during the construction stage *sparked* by the remarkably low defects rate in the biological cell proliferation process.

3. The journey – Research paradigm issues

3.1 The spark – Use of simile and the birth of the *construction as biological cells* simile

The inspiration for this study came from the use of simile and metaphor for research and teaching by the first author. The roots of this approach can be traced to the first author's study on Sri Lankan brickwork using reflecting on the simile *Brickwork as Chaos* (Abeysekera, 1997). The second study involved building theories on monetary retentions vis-à-vis the similes - *Retention as Cash Cow, Steroid, Beast, Stress and Chaos* (Abeysekera, 2008) based on research undertaken on monetary retentions. In the former study, Abeysekera investigated strategies for managing Sri Lankan brickwork with unprecedented and disorderly variations in brick and joint sizes including wall widths. He was inspired by Chaos **Theory** almost halfway through his study when he realised that what was studying was a very chaotic phenomenon. The discovery of *chaos theory* ***sparked*** a new line of investigation and an approach for finding solutions to a perennial problem. Paradoxically, this study found that despite the chaos, i.e. the disorderliness of brickwork operations, there was an underlying order while proposing a framework for finding the way through this chaos. In the second study mentioned above, i.e. on retentions, the attempt was to capture and condense a large body of evidence-based-knowledge to tell a *story* on monetary retentions generating new insights on how to manage retentions.

On both occasions, the first author contends that the *similes* were born out of adversity through *intuitive and reflective imagination and inference* (Evans and Frankish, 2009); it seems relatively simple now but their synthesis was challenging then requiring wild but creative flights of imagination. Encouraged by these pursuits, the first author argued that this approach may be a useful way to capture and condense the extensive knowledge on the *nature of construction* when faced with the daunting task of introducing the topic to first year construction management students at University of Southern Queensland. It transpired that simile and metaphor may provide some relief in encapsulating such a large body of knowledge into just one lecture! Accordingly, the topic was introduced through what was labelled as *images of construction* such as *Construction as Business, Construction as Machine, Craft and Industry* and so on. These *similes* proved very resourceful, and insightful too. Further explorations lead to the synthesis of the *construction as biological cells* simile as construction 'cells' are replicated in similar ways to biological cells (symbolically) to create a multi-cellular structure. Indeed, it appeared to be an interesting and powerful simile to explore the nature of cellular construction. While this lay dormant for a while, it was only through further exploration with the assistance of the second author who was employed in a quality management role in a first-tier construction company that it was discovered that biological cells do proliferate with a remarkably low error/defects providing the ***spark*** for the exploration of a seemingly **irrational but interesting challenge** in order reduce (or eliminate) defects in cell replication. Thus, began this study.

3.2 Study of *Construction as Biological Cells*: The initial research agenda

As noted above, the confidence to explore this simile was sparked by the discovery of the low defects rates of biological cells. Accordingly, it was fundamentally important to understand biological cell theory (BCT) – a seemingly daunting task for those with academic qualifications in engineering and construction management. Initial investigations revealed that construction cells do share properties similar to biological cells (Abeysekera & Shelke, 2015a), and it was useful to explore factors responsible for the defect free (i.e. quality) replication of biological cell. These investigations lead to the discovery of three main concepts: (a) Embedded design (b) Uniform rate of cell proliferation, and (c) Cell cycle control with the following objectives set to guide the investigation:

1. Undertake a detailed study of BCT	
2. Understand similarities of construction cells with biological cells	5. Establish quality management practices for managing quality in construction cells
3. Compare current practice with cell theory concepts, processes, and procedures	6. Synthesise potential drivers and solutions for change
4. Understand the reasons for deviations between cellular practice and construction practice	7. Establish the relevance of the newly identified drivers/solutions to construction

One of the challenges faced initially was the inability to see how this research could be conducted. As noted, the discovery that biological cells proliferate with a remarkably low error rate sparked the investigation and the need to investigate BCT was triggered by it. The desire to synthesise a suitable set of concepts came by reflecting on the *brickwork as chaos* study whereby concepts such as universalism, geometry of order, orderly chaos, etc. were synthesised for the development of the eventual framework. However, in this study, the researchers weren't sure whether this would be possible although a first round of study came up with the three concepts mentioned in the introductory paragraph. On reflection, the approach adopted seems to be conveyed by the simile *methodology (map) as spiral cone* described below.

3.3 Methodology (map) as spiral

Fig. 1: Methodology (map) as spiral

The sub-objectives set up earlier (see 3.2) is almost in a sequential and chronological order with one completed before the next is accomplished. Setting up all objectives accurately in one attempt is difficult if not impossible due to the lack of clarity what and how it needs to be done. This approach seems analogous with climbing a spiral (see Figure 1) in that the very nature of the spiral is such that it is difficult to see the destination when standing on one; the only way to see the top is to traverse spiral by spiral from one to another. Moreover, it is only when one spiral is traversed that the next can be seen albeit in a hazy environment but one with a sense of freshness as when the sun shines through on a misty morning. On further reflection, the road to success wasn't a straightforward path nor a simple input-output mechanism but one which was difficult to see with each spiral of knowledge helping to see the other filled with new discoveries, new concepts and development as shown in Figure 2 with the refined objectives as noted in Table 1

Table 1: Spiral of knowledge

1. Review Biological Cell Theory (BCT)	6. Document current quality management practices (as a participant observer)
2. Synthesise relevant concepts from BCT for exploration	7. Understand process mechanisms for cell division vis-à-vis BCC
3. Review literature on the use of simile and metaphor including similarities and dissimilarities between simile and metaphor	8. Synthesise a cell-based framework for managing quality in construction through intuitive and reflective inferences
4. Establish the feasibility of exploring the simile and metaphor particularly the construction as biological cells simile	9. Explore the application of its relevance including the relevant biological cell based concepts for construction
5. Understand the similarities of construction cells with biological cells	10. Establish the relevance of the newly identified drivers/solutions to construction and synthesise potential drivers and solutions for change

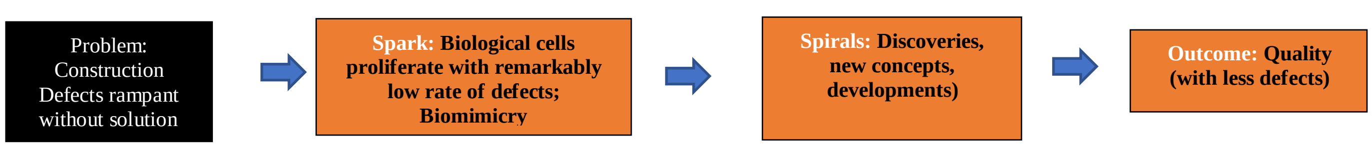
3.4 The simile cum metaphorical approach

Essentially, the approach adopted above involves comparing two seemingly dissimilar items to understand the similarities if possible and thereby generate new ways of thinking about items to generate new insights approaches for construction both in relation to technology and management with the intention of developing innovative solutions to perennial problems, or even frameworks for *understanding reality* in insightful ways. It is in this regard the use of *metaphor and simile* becomes a resourceful approach for understanding construction phenomena.

Table 2: The journey to date: Discoveries, new concepts, and developments

	Pursuit/Publications		**Knowledge area**	**Discoveries/New concepts/Developments**	**Methods (mainly as** participant observer)
	Summarised name	Year			
Seventh cycle	**Biological Cell Surveillance: Implications on Construction Cells**	2018	Cell Cycle Surveillance Mechanism	Process stress, process memory, distress signalling to ensure process stop	Reflective case analysis of tunnel project based on synthesized concepts
Sixth cycle	**Construction as Biological Cells: An Exploratory Study**	2017: Journal paper		Synthesis of a new model for managing construction: **Readiness-Growth-Rest (RGR)**	A reflective analysis of papers from 2013 to 2017
Fifth cycle	**BCT-based interventions and the impact on quality**	2017		Transient cell cycle arrest (TCA), readiness checks, embedded design; NCR based cell TCAs	Case study of a large transmission tower construction project
Fourth spiral	**Understanding the relevance of BCT and BCC for solving quality problems in construction**	2017	BCT and BCC	Risk assessment associated with lack of initial construction cell which exists as an abstract form given the loss in translation of design intent; dual rate and multi-phase approach with initial low rate to perfect the replication leading to stable build rate; congruity between design codes and translated codes at the construction coal face	Reflective case analysis of tunnel slab construction in large project to understand relevance of BCT and BCC; comparison of the current Quality Management practices in large projects with that employed in the biological cell
Third spiral	**Implications of the Biological Cell Cycle (BCC) for managing quality in construction**	2015	Biological cell cycle (BCC)	Biological cell control mechanism; embedded design imprinted through a ***multi-staged cyclic*** process with *gated* controls for detecting design deficiencies (different to PDCA cycle); process ***halted*** when defects detected and corrected.	Intuitive and reflective analysis of quality issues (Evans & Frankish, 2009) ; further exploring the notion of construction cell as biological cell
Second spiral	**Can construction cells be similar to biological cells?**	2015		***Types*** of construction cells identified; uniform rates of cell proliferation in construction cells with rate variations seemingly connected with defects; possibility to identify embedded designs with repetitive cells even in remotely possible cases; **simile cum metaphorical paradigm relevant** for *cell-based construction*	Multiple case studies with examples drawn to support the use of the simile cum metaphorical approach
First spiral	**Managing Quality in Construction:** Construction as Biological Cells	2013	Biological Cell Theory (BCT)	Cell - a basic unit of construction; cell proliferation – uniform with variations leading to cancer; process – driven by an embedded design	Case study of a large tunnel construction project with quality problems and significant variations in construction output seemingly correlated with number of NCRs

Source (of spiral): https://hu.123rf.com/profile_anhoog?mediapopup=11121167



3.4.1 Ontological issues

A *metaphor* is the expression of an understanding of one concept in terms of another concept, where there is some similarity or correlation between the two; it can also be used to understand one concept in terms of another as in *she is a peacock* or *time is money*. Similar to metaphor, *simile* is also a comparison between two things but expressed by the use of words *like* or *as*. Some common examples are 'he is as busy as a bee' (working very hard) or 'she is tough as nails' (having physical strength).

Both metaphor and simile compares two different things in interesting ways but both are different in nature: Simile uses words such as *like* or *as* to draw a comparison and a metaphor simply states the comparison without using *like* or *as.* Accordingly, *Construction as Biological Cells* is a simile although it is pointed out by some that *simile* falls under the broad category of metaphor both of which is a trope – a figurative use of an expression Black, 1993; Lakoff, 1990; Lakoff & Johnson, 1980 cited in (Jacobs & Heracleous, 2006). Can the power of such expression be used to understand *reality?* What can be said to exist?

According to Babbie (2001), nature of reality is more complex than what can be imagined. Three different viewpoints are presented, namely, *premodern, modern,* and *postmodern* views of reality. According to the premodern view of reality, it is claimed that 'our early ancestors all assumed that they saw things as they really were'. They would say that gods reside in trees and if trees were felled, those who do would be cursed. However, as humans evolved, such notions were challenged; they came to recognize that there were other views. This is the modern view of reality as different people have different views; there is nothing right or wrong although it seems to be a view that focusses largely on rationalism, logic and science to inform reality. A rose is a rose although in reality some may view it as beautiful but others as a thorn. In contrast, the postmodern view, according to Babbie (2001) holds that gods do not exist, neither does a rose; 'all that's "real" are the images we get through our points of view'. It seems to be all in the minds of human beings. While an attempt is made to understand what is "really" happening, as human being, they 'bring along personal orientations that will colour what they observe and how they explain it. There is ultimately no way people can step outside their humanness to see and understand the world as it "really" is – that is independently of all human viewpoints' and that 'there is no "objective" reality to be observed in the first place; there are only our several subjective views'.

In this regard, the authors contend that the nature of reality as understood through the *simile cum metaphorical* approach aligns with the *postmodern* view of ontology. In this sense, reality is seen as a projection of human imagination according to Hussey and Hussey (1997, p. 51), as in the use of the simile *construction as biological cells* – an image of construction similar to *Brickwork as Chaos or Retentions as Beast, Steroid, Cash Cow etc*. as referred to by (Abeysekera, 1997, 2008). It is an interesting *image* to be explored for creating new knowledge on *quality management* inspired by previous studies in construction management as noted above and described later with the power to develop innovative solutions perennial construction problems by making a difference to practice.

3.4.2 Epistemological issues

Creating knowledge has been a perennial challenge with significant ongoing debate among philosophers on *Theory of Knowledge* - on the nature of *theory*, its form, the manner in which knowledge should be created. Interestingly, *epistemology* is the branch of Philosophy concerned with the *theory of knowledge.* Strikingly, its body of knowledge is vast, so to profess knowledge about it would be false; yet, the situation demands a basic understanding of this complex branch of study with regards to methods, their validity, justified beliefs and opinion but from the context of a practical discipline such as construction management. Epistemology is said to address such questions as: *What does it mean to say that we know something? How do we know that we know?*

In other words, *knowledge* is about *knowing,* and in the context of this study, author's take the pragmatic position that what is important to practitioners is to *know* how to manage construction quality in ways that we will not encounter quality problems, or else to find ways to prevent the occurrence of existing quality problems – say defects, for example. One wonders whether we really *know* judging by the plethora of quality problems we encounter on a daily basis (Love et al., 2017). Perhaps, it is due to the *partial knowledge* we have and our *beliefs* are not *justified*. Accordingly, one may argue that theoretical underpinnings connected with quality management are weak. Thus, what needs to be borne in mind is that when using simile particularly the simile of *construction as biological cells* for creating new knowledge, it would be necessary to address issues related to epistemological questions as raised in the aforementioned paragraph.

It must be said that there are many ways of *knowing* such as authority, intuition, tenacity or even experience. Interestingly, according to the Webster's New World Dictionary, the word science which is derived from the Latin word *sciens* means 'knowing'. However, what makes science different to other ways of knowing is that 'science applies logic [reason] to questions constantly' for right understanding (Shoemaker, Tankard Jr, & Lasorsa, 2003). It is proposed therefore that knowledge created **must be science** if it is to be of value to professions involved with the built environment. Professions that are backed by knowledge (as science) could then be referred to as scientific, as in scientific engineering (as against engineering) analogous with 'scientific medicine' or 'scientific farming' (Miettinen, 2001). Accordingly, professional practice must necessarily become *scientific practice;* indeed, it is said that practice that is not driven by science is akin to a quack-doctor practicing medicine Berg (1995) as quoted in (Abeysekera, 2008). Accordingly, when exploring the simile *construction as biological cells*, we assert that what is required is to apply *logic* to questions constantly in *justifiable* ways with a 'specially firm determination not to persist in error if any exertion of hand or mind can deliver us from it' as noted by the Nobel Laureate biologist Peter Medawar with respect to the scientific method (Abeysekera, 2008). This does not necessarily mean that this study advocates the scientific method per se for creating knowledge but rather a case of drawing useful aspects from the scientific method for generating justified beliefs from the imagination/point of view of the researchers while aligning with the ontological view of post modernism; the 'truth' in this sense is seen as an imagination of the researchers: There is no *objective reality;* there are only our several subjective views.

4 The future – Methodological issues

Although the initial spark was the discovery that biological cells proliferate with a remarkably low error rate, the exploration of construction as biological cells has created a number of opportunities to explore further. One of the principle outcomes thus far is the synthesis of a new framework for production management called the Readiness-Growth-Rest model shown in Figure 2 (Abeysekera & Shelke, 2017). Whilst the model can be explored in relation to time, cost, quality and safety perspectives for achieving successful project outcomes, this study focuses on quality with a focus on minimising defects. This approach does not necessarily fit in with either an *inductive* or a *deductive* approach in the purest sense but the investigation in the future would fall broadly within the deductive approach but the approach in essence is different as shown in Figure 2.

Problematic phenomenon (observation) → **Generation of new concepts/models** (creating theory mainly through conceptual observations, reflections and synthesis using the simile cum metaphorical approach but partly through empirical observations/validation) → **Establishing the link between the model** (with associated concepts) to **future practice** in a way that we could call "practice as scientific practice" (see explanation in the paper)

Figure 2: Research Paradigm in a nutshell

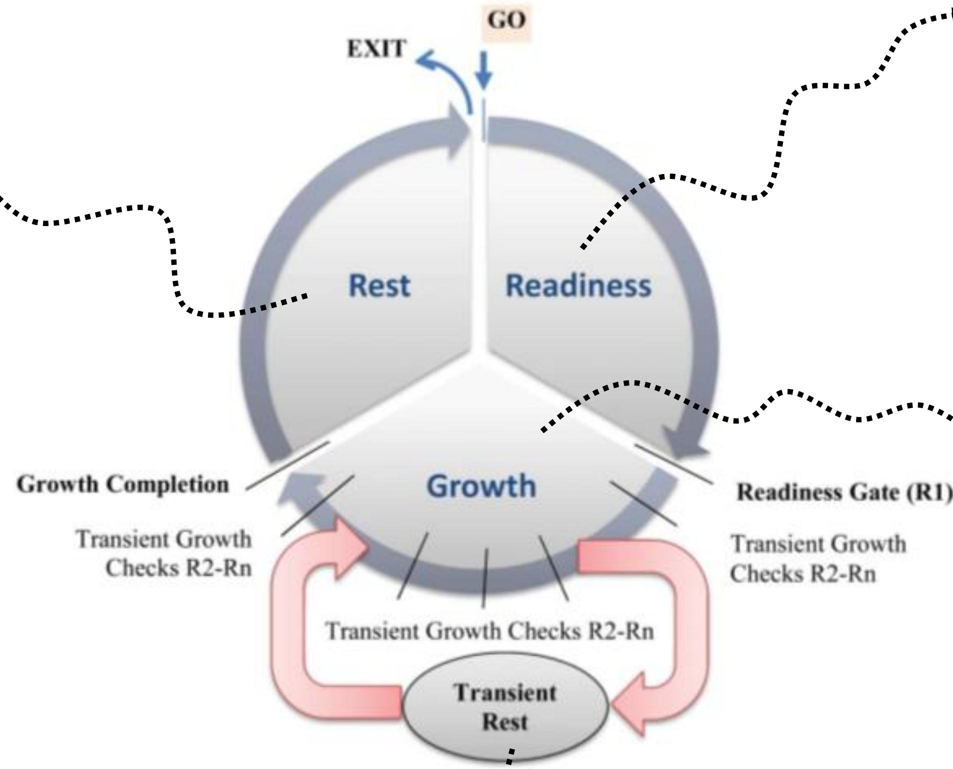
In order to advance the study further five methodological approaches have been proposed herein from which one has to be selected. These approaches are listed next for exploring the RGR model and the cell-based concepts which is to be finalised/chosen in due course with further reflection and analysis.

***Rest* concepts**

- *Perfect cell replication (no defects or time-related defects)*
- *Gate failures*
- *Abnormal cell proliferation rates*
- *Cancerous cells: Detection and destruction*
- *Cell senescence*

***Readiness* concepts**

- *Embedded design (EMD) for process*
- *EMD for quality (nature, form, style)*
- *EMD feasibility, suitability, acceptability*
- *Trialling and testing of EMD*
- *Process readiness*
- *Readiness gate(s)*



***Growth* concepts**

- *Uninform/multi-rate cell proliferation*
- *Process stability*
- *Process stress - Distress signalling to induce transient rest*
- *Abnormal rate of cell proliferation (low/high)*
- *Cell surveillance (EMD compliance, translation, transliteration, real time)*
- *Growth gates (multiple)*
- *Process memory (data analytics)*
- *Transient gate(s)*
- *Functional redundancy Feedback stabilization*
- *Emergent or self-organization*

***Transient-Rest* concepts**

- *Cell senescence (Transient rest - a forced state of rest)*
- *Cell progress arrest (embedded design is not replicated correctly*
- *Cell triggers for process arrest (e.g. NCR threshold, process stress vis-a-vis cell instability)*
- *Cell repair/restoration*

Figure 3: A conceptual framework for exploring RGR model to achieve Quality (zero defects)
Source of RGR model: (See, Abeysekera & Shelke, 2017)

Option 1: As participant-observer (PO) re-evaluate case study projects using RGR model
This study has thus far used data connected with three large projects viz. tunnel slab construction, coal export terminus, and a 275kV transmission line tower erection. The first author has been involved with all three projects as the Quality Coordinator for these project. Accordingly, one option is to re-analyze these projects with the new findings with the aim of changing existing practice. The basic question to answer is 'what the PO would have done differently to reduce the quality problems encountered in these projects?' The results would then be evaluated seeking views of senior project personnel to establish the feasibility of the proposed solutions.

Option 2: Apply RGR model to a new project and assess impact (as in action-research)
Use the RGR model along with the new concepts and apply these to a new project. This will require negotiating with project personnel to establish what is acceptable and what is not. This will give an understanding of its application feasibility. If benchmarking data are available, it may be helpful. Further discussions will be held with project personnel throughout the project and at the end to understand their perceptions on whether in fact, the application of the model along with the new concepts had made a difference.

Option 3: Semi-structured interviews and focus group meetings to evaluate RGR
Undertake a survey to evaluate the feasibility model implementation along with the associated concepts. Experienced and well-respected participants will be selected along with focus group meetings with selected/invited participants. The focus will be the usefulness of the model and the concepts with the goal of reducing quality defects.

Option 4: Application of RGR (and concepts) to problematic processes as a PO (similar to Option 1)
Focus on three repetitive processes (in essence of a cellular nature) which are known to produce defects (with high frequency and impact) and assess the suitability of the RGR model (and concepts) to understand their relevance for reducing defects. Historical data pertaining to defects (for example, processes that results in higher number of NCRs, high quality costs, etc.) will be used for the selection of repetitive processes. Problems arising will be viewed through the model developed with the application of the concepts with the hope of bringing about change. The results will be evaluated seeking views of senior project personnel to establish the feasibility of the proposed solutions.

Option 5: Application of RGR (and concepts) to problematic processes and assess impact (similar to Option 2)

Option 6: Application of RGR (and concepts) to an on-going project as a PO (as in options 1 & 2)

Option 7: Application of RGR (and concepts) to an on-going project and processes (as in options 1 & 2)

These options need to be evaluated in due course selecting the best option to assess the relevance of the RGR framework and the associated concepts.

6. The research paradigm in a nutshell

This study has shown how similes could be used for investigating a perennial construction phenomenon and the ontological and epistemological considerations when using this approach. It argues that the approach is neither inductive nor deductive presenting it as a hybrid approach for building *theory as practice* particularly *practice as science* to generate *scientific-practice*. The *methodology (map) as spiral* reflects on the nature of the challenge with methodologies presented as options (1 to 6) with one to be selected. Different research methods such as interviews, action research, and case study etc. may be used to achieve original study objectives. As noted herein, once a suitable option is selected and explored, it is hoped that it would generate new knowledge on how to manage quality in *cellular-construction* with a greater reduction of defects than now possible.

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The Tenth International Conference on Construction in the 21st Century (CITC-10)
July 2nd-4th, 2018, Colombo, Sri Lanka

Life-Cycle Cost Analysis of Energy Efficient Single Family Homes in Pakistan

Salman Azhar, Kamal Ahmed, Amna Salman
McWhorter School of Building Science, Auburn University, Auburn, Alabama, USA

Abstract

This paper is a companion of our first paper titled "Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan" which is also published in this conference proceedings. It presents results of Life-Cycle Cost Analysis (LCCA) of baseline and improved designs with energy efficiency measures for single family detached homes in Pakistan. The LCCA is an important tool to determine the feasibility of any energy efficient measure in the design process. It takes into account all costs of acquiring, owning, and disposing of a building or building system. By comparing LCCA of an existing design with a proposed design we can find out if the design updates are going to be economical in the long run. It includes initial investment, operating and maintenance, and disposal costs. The efforts made to minimize the life-cycle costs are not only beneficial for building owners but also for the society and economy. In our research, the LCCA results showed that, over the lifetime of the building, four measures namely Lighting Power (LEDs usage), White Paint on Roof, Roof Insulation and Exterior Wall Insulation are economically feasible. The LCCA results further indicated that the combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years of building's service life. It is strongly recommended that various energy efficiency measures should be implemented in residential designs in Pakistan. The Implementation process will require continuous effort from government, housing authorities, designers, contractors and homeowners. The LCCA results produced as part of this research can be used as a benchmark. In addition, the LCCA for more energy efficient products should be carried out in an effort to fully understand their economic impact as well as short and long-term feasibility.

Keywords

Life-cycle, Life-Cycle Cost Analysis (LCCA), Life-Cycle Costing (LCC), Return on Investment (ROI), Energy efficient design, Residential construction

1. Introduction

The Life-Cycle Cost Analysis (LCCA) is considered as an important decision tool in the planning and designing process of the buildings. This tool is used to analyze the effectiveness of different Energy Efficient Measures (EEMs) in the building. In the construction of buildings, the initial investment in production cost is commonly set to minimum which does not necessarily results in a decrease in the life-cycle cost of a building. It becomes very important to show to the clients and owners of the building the relationship between efficient design choices and resulting life-cost of the building (Leckner and Zmeureanu, 2011). This issue becomes even more prudent when it comes to residential buildings. Owner of residential buildings and homes are most concerned with the initial investment they have to make for the completion of the project. In doing so, they tend to ignore the life-cycle cost of the building which often rises if initial planning is not very well thought out.

The LCCA is an important tool to determine the feasibility of any energy efficient measure in the design. "Life-Cycle Cost Analysis (LCCA) is a method for assessing the total cost of facility ownership. It takes into account all costs of acquiring, owning, and disposing of a building or building system" (WBDG website, 2016). By comparing LCCA of an existing design with a proposed design one can find out if the design updates are going to be economical in the long run. It includes initial investment, operating and maintenance, and disposal costs. The efforts made to minimize the life-cycle costs are not only beneficial for building owners but also for the society and economy. However, regardless of its importance, Life-Cycle Costing (LCC) has found limited applications so far. The reason for lack of applications of LCC is two barriers that include the complexity of the LCC technique and shortage of LCC data (Motuzienė et al., 2016). LCCA is being extensively used for industrial products nowadays (Levander et. al 2014). The goal is to minimize the production cost and maximize the profit. There are several differences between industrial products and buildings or homes. One of the major difference is the life length of a building compared to the industrial product. These factors can make the initial LCCA more difficult in the case of buildings or homes (Leckner and Zmeureanu, 2011).

The consumption of energy in an office building over a 25-year span will be almost three times the initial cost, but still more attention is paid to initial capital cost. The important point to note here is that a higher production cost can decrease the LCC. It is very important in the planning phase to show the relation between design choices and resulting life-cycle costs so that the owner can make appropriate decisions before the construction process starts (Schade, 2007). The execution of energy efficiency measures is becoming ever more important considering the amount of energy buildings are utilizing. An LCCA was conducted on residential buildings in Romania. The goal of this LCCA was to analyze the cost effectiveness of initial investment in renewable energy resources. The study was conducted on houses having low energy demand. It studied the impact of using photovoltaic panels on a passive house. The initial investment increased by 9.1% after incorporating photovoltaic cells. The results of this study showed that the application of photovoltaic cells is a cost-effective solution for electricity production leading to a payback period of 8-11 years. In studies considering the use phase, the life length of the house is an important consideration. The life length is generally determined by how long the residents tend to stay in a house, the functional lifetime of the house/building itself, or the length of time for a generation to pass. The Life length varied from 25 – 100 years in the literature assessed, most falling between 30-50 years (Leckner and Zmeureanu, 2011).

2. Aim and Scope

The aim of this paper is to conduct and compare LCCA of baseline designs and improved designs with energy efficiency measures for single family detached homes in Pakistan. The key question for this study is as follows: "Are initial investments for energy efficient design and construction feasible considering life cycle costs of a building?". This research is limited to design development of single family detached homes in Pakistan. Size of these homes ranges from 800 to 6000 sq. ft. The weather conditions considered for this research are of hot climate areas. Moreover, the focus city for this research is Lahore (31° 32′ 59″ N, 74° 20′ 37″ E) which is the 2nd largest city of Pakistan and lies in hot climatic region where summer season dictates the type of design. It is important to note that this paper is a companion of our first paper titled "Development and Testing of Energy Efficient Designs for Single Family Homes in Pakistan" which is also published in this conference proceedings (see Azhar *et al*, 2018a). Please refer to the first paper to learn about various Energy Efficiency Measures (EEMs) proposed in the base designs.

3. Literature Review

A short literature review in the form of three case studies was conducted. The three case studies discussed three different aspects involved in the LCCA. The first case study was focused on data uncertainties involved in the LCCA and how this data can impact the final results (Giuseppe et. al., 2017). Economic parameters like inflation rate, interest rate and energy price evolution play an important role in the determination of life-cycle cost of any energy efficient measure. The authors suggested that the probabilistic LCC methodologies could provide powerful decision support for undertaking building energy efficiency measures and should be used in the LCCA (Giuseppe et. al., 2017).

In the second case study, implications of different roofing and floor designs are considered on the life-cycle cost of the building (Islam et. al. 2015). The researchers divided the life of the building into four phases; construction, operation, maintenance, and disposal. The results showed that after incorporating the design improvements, the overall cost is reduced in the first three phases of the building whereas in the disposal phase the costs were increased. However, the overall life-cycle cost remained below the life-cycle cost of the base design.

In the third case study, building orientation and passive heating/cooling techniques were analyzed to determine their cost impact over the life-cycle of the building (Satori and Hestnes, 2006). The research compared results of 60 different houses from different climatic conditions. The LCCA results showed that houses incorporating passive techniques were more energy efficient over the entire life-cycle. In conclusions, all the three case studies indicated that a higher initial investment in energy efficient measures is economically feasible over the course of life-cycle of the building.

4. Research Design and Methodology

The research design is outlined in Figure 1. The first two phases of research are already explained in the first paper (see Azhar *et al*, 2018a). In the last phase, the LCCA was conducted to evaluate the feasibility of a design feature over the course of life span of a house (steps marked in bold) and final recommendations are made.

Figure 1. Research design

The LCCA was performed using data from energy simulations of existing and proposed design solutions. The results of the LCCA indicate if a design solution is effective and beneficial over the course of its life cycle. The first step in LCCA is to determine the economic impact of an alternative design or improved design. The Life cycle costs include initial cost, energy and water usage costs, operation and maintenance costs, replacement costs, residual value and other costs like taxes etc. After determining all these costs, one can calculate the life cycle costs (Dell'Isola, 1997).

For LCCA, the Present Value method was used. In the Present Value method, all present and future costs are converted into baseline of today's costs. Initial costs are expressed as present worth. Net present value is the difference between the present value of cash inflows and the present value of cash outflows that occur as a result of undertaking an investment project (Dell'Isola, 1997).

The following formula is used for Present Value calculations (Dell'Isola, 1997):

$$PV = \frac{FV}{(1+i)^n} \qquad \text{(Equation 1)}$$

Where:
- *PV* is Present Value
- *FV* is Future Value
- *i* is the interest rate (as a decimal)
- *n* is the number of years

The unit rates of all design items were collected from open market and vendors in Pakistan. Interest rate is assumed to be 6% (Trading Economics Website, 2017).

5. Results and Discussion

As mentioned in the first paper (see Azhar *et al*, 2018a), the following design measures were found to be most effective for achieving maximum energy savings:

1. Lighting Power (LEDs usage)
2. White Paint on Roof
3. Roof Insulation
4. Exterior Wall Insulation

Hence the LCCA was conducted for these measures only.

5.1 Lighting Power (LEDs Usage)

Replacing CFLs with LEDs resulted in the most savings in electricity bills. Price of CFL and LED light fixtures were collected from vendors in Pakistan. The manufacturer used for pricing of lighting fixture was Philips. The prices were PKR 175 and PKR 240 for one 24W CFL and one 9W LED respectively. The number of lighting fixtures per space were assumed based on the common practices used in Pakistan. The extra cost of LEDs from CFLs was considered as initial investment for this measure. For replacement costs, it was assumed that CFLs will be replaced every 2.5 years and LEDs will be replaced after every 10 years. Table 1 shows initial investment, annual savings and lifetime savings for each home. The replacement costs for CFLs were higher than the LEDs, this difference in replacement costs was added to Net Lifetime Savings. The LCCA results indicate that the initial investment for the LED usage will be recovered during the first year of building's service life for all homes.

Table 1: Lifetime Savings from LEDs Usage

z	I		Y		L		N=L-I+ Replacement Costs	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Lifetime Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	1,950	19	6,639	63	524,867	4,999	543,048	4,980
Home B	3,575	34	7,841	75	619,895	5,904	653,226	5,870
Home C	5,200	50	14,202	135	1,122,784	10,693	1,122,965	10,644
Home D	8,775	84	42,869	408	3,389,145	32,278	3,470,957	32,194

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.2 White Paint on Roof

The second energy efficiency measure considered for the LCCA was the application of white paint on roof. In the calculations, it was assumed that applied paint is white weather resistant paint by *Master Paints*. Two coatings of paint were applied with 0.0172 liter paint per square foot. The total initial cost for paint was calculated using total roof area and price per liter. It was also assumed that the roof surface will be re-painted after every 3 years over the lifetime of building. All future replacement costs were converted into present values for the LCCA. The initial investment and replacement costs for paint application were PKR 44,777, PKR 72,796, PKR 137,351 and PKR 280,195 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 5,464, PKR 6,242, PKR 9,205 and PKR 21,435 for Home A, Home B, Home C, and Home D respectively. Table 2 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicates that initial investment and replacements costs for paint usage will be recovered during the 10^{th}, 13^{th}, 16^{th} and 13^{th} year of building's service life for Home A, B, C, and D respectively.

Table 2: Lifetime Savings from White Paint on Roof

Home	I		Y		L		N=L -I + Replacement Costs	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	44,777	426	5,464	52	431,974	4,114	387,197	3,688
Home B	72,796	693	6,242	59	493,481	4,700	420,685	4,007
Home C	137,351	1308	9,205	88	727,731	6,931	590,380	5,623
Home D	280,195	2669	21,435	204	2,010,845	19,151	1,730,650	16,482

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.3 Roof Insulation

The third energy efficiency measure considered for LCCA was installation of 2 inch roof insulation. In the calculations, it was assumed that installed insulation product is *Diamond Jumbolon*®. The total initial cost for roof insulation was calculated using total roof area and insulation price per square foot. The initial investment for roof insulation was PKR 74,980, PKR 121,900, PKR 230,000 and PKR 469,200 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 2,884, PKR 2,571, PKR 4,603 and PKR 8,548 for Home A, B, C and D respectively. LCCA was carried out using the PV method. Table 3 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicate that initial investment for roof insulation will be recovered during the 16^{th}, 28^{th}, 24^{th} and 25^{th} year of building's service life for Home A, B, C and D respectively.

Table 3: Lifetime Savings from Roof Insulation

Home	I		Y		L		N=L-I	
	Initial Investment		Yearly Savings		Lifetime Savings		Net Savings	
	PKR	USD	PKR	USD	PKR	USD	PKR	USD
Home A	74,980	714	2,884	27	228,004	2,171	153,024	1,457
Home B	121,900	1161	2,571	24	145,230	1,383	23,330	222
Home C	230,000	2190	4,603	44	363,905	3,466	133,905	1,275
Home D	469,200	4469	8,548	81	675,789	6,436	206,589	1,968

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.4 Exterior Wall Insulation

The last energy efficiency measure considered for the LCCA was installation of insulation on exterior walls. In the calculations, it was assumed that the installed insulation product is *Diamond Jumbolon*®. The total initial cost for insulation was calculated using total surface area of walls and insulation price per square foot. The initial investment for exterior wall insulation was PKR 30,814, PKR 61,628, PKR

136,462 and PKR 181,618 for Home A, B, C and D respectively. The yearly savings in electricity bills were PKR 175, PKR 1,840, PKR 1,736 and PKR 2,762 for Home A, B, C, and D respectively. Table 4 shows initial investment, annual savings and lifetime savings for each home. The LCCA results indicate that initial investment for exterior wall insulation will be recovered during the 19th, 30th and 28th of building's service life for Home B, C, and D respectively. For Home A, It was observed that although wall insulation had some annual savings but its life cycle cost was more than the cumulative savings. It was due to the reason that Home A had very low exterior wall area for wall insulation which contributed to lower savings.

Table 4: Lifetime Savings from Exterior Wall Insulation

Home	I Initial Investment		Y Yearly Savings		L Lifetime Savings		N=L-I Net Savings	
	PKR	**USD**	**PKR**	**USD**	**PKR**	**USD**	**PKR**	**USD**
Home A	30,814	293	175	2	13,835	132	-16,979	-162
Home B	61,628	587	1,840	18	145,467	1,385	83,839	798
Home C	136,462	1300	1,736	17	137,245	1,307	783	7
Home D	181,618	1730	2,762	26	218,359	2,080	36,741	350

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

5.5 Combined LCCA Results for Energy Efficiency Measures

In the last step, the LCCA was conducted to see the combined impact of following energy efficiency measures.

1. Lighting Power (LED usage)
2. White Paint on Roof
3. Roof Insulation
4. Exterior Wall Insulation

The combined initial investment for all energy efficiency measures was PKR 116,155, PKR 200,777, PKR 397,462 and PKR 712,225 for Home A, B, C, and D respectively. The yearly savings in electricity bills were PKR 15,162, PKR 18,494, PKR 29,746 and PKR 75,614 for Home A, B, C and D. Table 5 shows initial investment, annual savings, and lifetime savings for each home whereas Figures 2, 3, 4 and 5 show LCCA charts for Home A, B, C and D respectively. The LCCA results indicate that combined initial investment for all energy efficiency measures will be recovered during the 7th, 9th, 10th and 8th year of building's service life for Home A, B, C, and D respectively.

Table 5: Combined Lifetime Savings from Energy Efficiency Measures

Home	I Initial Investment		Y Yearly Savings		L Lifetime Savings		N=L-I Net Savings	
	PKR	**USD**	**PKR**	**USD**	**PKR**	**USD**	**PKR**	**USD**
Home A	116,155	1106	15,162	144	1,198,680	11,416	1,082,525	10,310
Home B	200,777	1912	18,494	176	1,462,102	13,925	1,261,325	12,013
Home C	397,462	3785	29,746	283	2,351,665	22,397	1,954,203	18,611
Home D	712,225	6783	75,614	720	5,977,906	56,392	5,265,681	50,149

(Currency exchange rate: 1 US$ = PKR 105.4 as in July 2017).

Home A

Home B

Home C

Home D

Figure 2: Combined LCCA Results for Energy Efficiency Measures

6. Conclusions and Recommendations

This paper presented Life-Cycle Cost Analysis (LCCA) of energy efficient designs for typical single family detached homes in Pakistan. The energy simulation results (see Azhar et al., 2018a) showed that all energy efficiency measures resulted in some reduction in electricity consumption. However, the LCCA results showed that, over the lifetime of the building, four measures namely Lighting Power (LEDs usage), White Paint on Roof, Roof Insulation and Exterior Wall Insulation are economically feasible. The LCCA results further indicated that the combined initial investment for these energy efficiency measures can be recovered within 7 to 10 years building's service life. It is strongly recommended that various energy efficiency measures are implemented in residential designs in Pakistan. The implementation process will require continuous effort from government, housing authorities, designers, contractors and homeowners. Some of the energy efficiency measures like LED usage and White Paint on roof can be made mandatory in house construction as they have lower initial cost and biggest savings. Moreover, homeowners and builders should consider these energy efficiency measures in the planning phase because they will save their money in the long run and also save country's electricity production. The LCCA results produced as part of this research can be used as a benchmark. In addition, the LCCA for more energy efficient products should be carried out in an effort to fully understand their economic impact as well as short and long term feasibilities.

This research study provides an initial data for future studies. Future research studies can explore more areas of a residential home where electricity can be saved. Moreover, future research is needed on incorporating energy efficiency measures in housing codes and examine their implementation. After residential sector, commercial sector should also be considered so that electricity can be saved from those sectors. Future research can be conducted to study the impact of miscellaneous electricity loads on overall electricity consumption. These loads mainly include appliances like televisions, computers, microwave ovens, washer and dryers. There is potential for saving electricity if these appliances can be made more energy efficient.

7. Acknowledgment

This research study is funded by the US Department of State and the Higher Education Commission of Pakistan (HEC) under the joint Pakistan-U.S. Science and Technology Cooperation Program (Phase 6).

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Review on Photocatalysis Applications in Construction

Muhammad Yasir Sadiq
(Graduate student, East Carolina University, Greenville, NC, USA)
sadiqm18@students.ecu.edu

Amin K. Akhnoukh
(Associate Professor, East Carolina University, Greenville, North Carolina, USA)
akhnoukha17@ecu.edu

Abstract

Many construction projects are composed of concrete or mortar. After construction of such projects, the material faces challenges which cause aesthetic as well as physical deterioration. This paper discusses the application of Heterogeneous Photocatalysis which is a versatile, cost efficient and environmentally friendly treatment technology. The natural resources that are being used for demonstrating the self- cleaning characteristics of the photocatalytic materials is laudable. The most popularly used photocatalytic material is Titanium dioxide (TiO2).Multiple reasons are discussed for TiO_2 being beneficial for the construction industry. The principal utilization of TiO_2 as a photocatalytic building material is due to its self-cleaning, self-disinfecting and sustainability properties. The basic mechanism of photocatalysis is also analyzed for actual understanding of the project. The photocatalytic application for a greener road environment is worth mentioning. The paper discusses that which type of TiO_2 coating is the most sustainable and best choice for an urban road environment which will efficiently eliminate the harmful nitrogen oxides (NO_x) and volatile organic compounds (VOCs). The effect of particle size on the cost and productivity of the photocatalytic material is mentioned. The variability of the coating mix with the reduction of NO_x and VOCs.

Keyword

Heterogeneous Photocatalysis, Titanium Dioxide, Pollution , Environment ,self-cleaning concrete

1. Introduction

The research on photocatalytic capability of a material and its applications has started to gain momentum from different aspects. The characteristics and the applications of the materials are undoubtedly a prudent choice for today's world where pollution is added in a proliferated amount because of vehicle and industry emissions. The photochemistry of TiO_2 has become a critical research subject for the future. Different research projects in the world are striving hard for a better, sustainable and green environment for our future generations. This subject gained momentum in research when the photocatalytic splitting of water on TiO_2 and Sr-doped TiO_2 respectively became successful in the 1970's. Two important effects related to nature of photoactive TiO_2 coatings had by this time been discovered a)- self-cleaning effect due to redox reactions promoted by sunlight (or in general weak U.V. light) on the photocatalytic surface and b)- the photo-induced super hydrophilicity of the catalyst surface, which enhances the self-cleaning effect(inorganics causing dirt and stains on surfaces can be easily removed due to rainwater soaking between the adsorbed substance and the TiO_2 surface). For the photocatalysis to initiate U.V. light is fundamental which means that this process will be more productive in the day time than in any other time. The solar energy reaching the earth's surface is about 5 x 10^{24} J per year. This is more than the 10^4 times the annual worldwide consumption of energy. This is the best part that we are using natural resources for this process. This enormous source of energy is utilized with exceptionally engineered construction materials which have the potential to make the environment cleaner and free of pollutants.

1.1 Photocatalysis

Photocatalysis is the photoreaction in the presence of a catalyst. The term "photocatalysis" is in widespread use and is here to stay; it is not meant to, nor should it ever be used to, imply catalysis by light, but rather the "acceleration of a photoreaction by the presence of a catalyst". The term "photoreaction" is sometimes elaborated on as a "photoinduced" or "photoactivated" reaction, all to the same effect (Mills and Hunte, 1997). The process of photocatalysis is very prominent in the presence of light as the photocatalytic efficiency of the building materials is visible. The study of photocatalytic reactions was initiated in 1970's. During the photocatalytic process light is consumed by one or two reacting species and this is the reason that catalyst is added which does not get consumed and accelerates the reaction.

1.2 Types of Photocatalysis

Photocatalysis is the acceleration of a photoreaction in the presence of light. There are two types of photocatalysis which are homogeneous and heterogeneous. Homogeneous photocatalysis, the reactants and photocatalyst exist in the same phase. In Heterogeneous photocatalysis, the reactants and photocatalyst exist in different phase from the reactants. The heterogeneous photocatalysis will be discussed in more detail later.

1.3 Heterogeneous Photocatalysis :-

Heterogeneous photocatalysis is based on the irradiation of a semiconductor photocatalyst in contact with a liquid or a gaseous environment. TiO2, ZnO, and CdS are widely used examples (Cassar,2004).

A band gap exists between the valence band and conduction band. The electron gets promoted form a valence band to the conduction band in the presence of Ultra violet radiation or fluorescent light. During promotion of electron from a valence band to conduction band a hole is left on the valence band. The holes oxidize the donor molecules. The energy of band gap is 3.2 ev.

$D + h^+ \rightarrow D^{\cdot +}$

Whereas the conduction band electrons can reduce appropriate electron acceptor molecules.

$A + e^- \rightarrow A^{\cdot -}$

The afore-mentioned explanation presents a brief description to the chemistry of the photochemical reaction in which TiO2 is seen as the photocatalyst.

2. TiO_2 as a Photocatalyst

TiO_2 is used as a photocatalyst. Although, there are several other metal oxides of vanadium, chromium, zinc, tin and cerium. TiO_2 has ample amount of applications such as it is most widely used inorganic pigment for varnishes and plastics. It is used as a white pigment in paints because of its strong resistance to discoloration under UV light. It is also used in foods, pharmaceuticals and cosmetics. The reason of using TiO_2 is that it

is very cost efficient and has the capability to go under quick reactions at ambient operating conditions (room temperature, atmospheric pressure). TiO_2 is also used as a photocatalyst because of being chemically stable and compatible with traditional construction materials such as cement. TiO_2 is very effective under weak solar irradiation in various conditions of the environment.
The reasons for using TiO_2 as a photocatalyst are that in addition to the self cleaning characteristics that it shows in the presence of light. It also introduces to its various other characteristics which are the anti-fogging effect, water treatment, air cleaning effect and anti-bacterial effect. Due to these reasons TiO_2 is considered as a very beneficial oxide in the industry. TiO_2 ceramic tiles are considered to be very effective against organic and inorganic materials and also towards bacteria. Hence when such applications of TiO_2 are seen then there comes no question in using any other metal oxide for photocatalytic process.

2.1 Forms of TiO_2

TiO_2 occurs naturally as rutile, brookite and anatase. Now the question comes that which one is the best for photocatalysis. Compared with rutile and brookite, anatase shows the highest photoactivity (Benedix *et al.*,2000).
Despite the intensive study of TiO_2 there is no generally accepted explanation for the differences of photocatalytic activity of different polymorphs or surface orientations. The general perception that anatase has a higher photocatalytic activity compared to rutile TiO_2 is confirmed by out measurements on extended planar epitaxial thin films . Anatase exhibits an indirect band gap that is smaller than its direct band gap. For rutile, on the other hand, its fundamental band gap is either direct or its indirect band gap is very similar to its direct band gap (Luttrell *et al.,* 2014). Anatase, the most commonly used photocatalyst in concrete, is capable, under natural sunlight, of degrading certain atmospheric pollutants, e.g. NO_x, Volatile organic compounds (VOCs) and non-volatile organic residues due to charge transfer (redox) processes on the catalyst surface (Macphee and Folli 2016). The previous researches suggest that anatase has more photocatalytic activity any other of its forms due to which it is used majorly in the environment.

2.2 Nano and Micro size particles

In relation to size TiO_2 can exist either in micro or nano size. The work done by various researchers suggest that the size has a solid effect on the photocatalytic efficiency of the material. At first nano particles were considered as a favorite choice for better results but latest research opposes this approach. Although TiO_2 is chemically inert, TiO_2 nanoparticles can cause negative health effects, such as respiratory tract cancer in rats (Trouiller B 2009) investigate TiO_2 nano particles- induced genotoxicity, oxidative DNA damage, and inflammation in a mice model. The increased use of nano materials in commercial products has raised a growing public debate on whether the environmental and social costs of nanotechnologies outweigh their numerous benefits (Colvin VL 2003). Up to now, few studies have investigated the toxicological and environment effects of direct and indirect exposure to nano materials and nano particles and no clear guidelines exist to quantify these effects (Hye Won K 2009). This research opens doors for the usage of micro sized TiO_2 powders instead of nanometric ones. They are cost efficient as well as safer for both the environment and the workers on the site which practically apply these materials as a coating on the materials such as concrete blocks or the different parts of the road for a better healthy environment which is more cleaner and free of bacteria. Traditionally it was thought that a decrease in particle size such as nano particle will perform better than micro particle. However the latest research suggests something else as health effects of nano particles cannot be compromised.

3- Applications of TiO_2

TiO_2 due to having various beneficial and prominent characteristics has various practical applications in the construction industry.

3.1 Residential and Commercial Construction

It is a common phenomenon that the aesthetic and luster of the surface of ordinary buildings are gradually lost with time. The building surface could be soiled by greasy and sticky deposits, which results in a strong adherence of ambient dusts. As a result, dirt built up on the surface reduces the visual appearance (Jun Chen 2009). The self-cleaning product having a coating of TiO_2 can save so much money for maintenance of such a dusty building and can be very cost effective. Hence the use of TiO_2 Besides self-cleaning cementitious materials, TiO2-based selfcleaning exterior building products including tiles and glass have been widely commercialized and applied. About 270 patents have been registered in the photocatalytic technology domain by TOTO Ltd (TOTO Ltd 2008). Another important commercial product among the photocatalytic building materials is TiO2 based self-cleaning glass. Its successful application is not only due to the self-cleaning function but also strengthened by the light-induced anti-fogging property. Fogging of the surfaces of mirrors or glass happens when steam is cooled down on the surface to form fine water droplets. As droplets fall or form on a hydrophilic surface, they rapidly coalesce to form a water sheet. The visible view behind the glass can still be observed without blockage or distortion. Moreover, the superhydrophilic layer makes the glass dry without leaving the traditional droplet marks (Sanderson K 2001). Similarly with these advancements, many other researches have been proposed which indicate a new method of cooling buildings by sprinkling water on the surface of buildings which are coated with TiO_2. This new application of photocatalytic building materials can result in significant reduction of electricity consumed for air conditioning (Hashimoto K 2005).

3.2 In an urban road environment

The UK is currently facing a fine of $500 million for London exceeding the PM10 particle pollution limits more than 35 times for the entire year (Olek J *et al*, 2003). This study proves the necessity of photocatalytic coating on a huge scale. Some benefits of photocatalytic concrete are that it decomposes chemicals that contribute to soiling and air pollution, keeps the concrete cleaner, and reflects much of the sun's heat and reduces heat gain because of its white color (Chusid M., 2006). However, a lot of work has been done to promote carpooling and better public transportation has been designed but still the vehicle emissions continue to grow in the environment due to which the importance of photocatalytic concrete cannot be neglected. It is to be noted that the contact of TiO_2 with sunlight is very important. Once they stay in contact then the photocatalytic effect becomes very prominent instead of having the TiO_2 mixture

within the concrete layer. If the TiO_2 coating is brushed on the top of the surface pavement then they seemed to be more durable in case of light pedestrian traffic whereas in case of high abrasion of vehicles the top coating of the TiO_2 seems to get abraded.

Table 1 Material Cost for each Coating Type (Shen *et al.* 2012)

Coating type	Material cost		Observed pollutant reduction			
	Total material cost ($/ft^2)	otal material cost ($/m^2)	Static chamber (120 min) Total% toluene reduction	Static chamber (120 min) otal% TMB reduction	Converted Static chamber (29.83 min) total% NO reduction	Decrease in infiltration rate (%)
Commercial water- ased TiO_2 (CWB)	0.9955	10.70	1.86 ± 14.06	4.64 ± 1.85	97.59	20.60
ement–water slurry (CWSH)	0.1860	2.00	3.23 ± 1.62	1.65 ± 1.50	85.04	58.29
Driveway protector mix (DPM)	0.3876	4.17	1.65 ± 10.77	3.87 ± 1.09	97.92	30.49
Pureti (PUR)	0.1000	1.08	3.42 ± 1.79	9.50 ± 4.05	95.79	11.92
ement–water slurry low (CWSL)	0.1655	1.78	8.82 ± 9.22	7.26 ± 0.63	96.94	51.50
Cement/aggregate mix (CAM)	0.3045	3.27	1.62 ± 4.30	8.28 ± 5.99	55.35	3.85
Cement/aggregate mix high (CAMH)	0.3030	3.26	-	–	81.03	3.49

Table 1 shows different coating types which have been mixed together with different concentrations of cement and other substances depending on the coating type. After the study of these different coating types Driveway protector mix was considered the best choice as it is a mixture which consists of a transparent liquid drive way protector (siliconate, water-based concrete sealer) and TiO_2 uniformly mixed together and brushed on to the surface of pervious concrete (Shen *et al.*, 2012). The conclusions of this table suggest that DPM is the best mixture as compared to cost efficiency and performance of its photocatalytic capability. The highest reduction in pollutants and the highest resistance to weathering can be seen with this mixture which is a breakthrough for the photocatalytic research. The white color of the TiO_2 particles seen in the DPM coating could potentially be used as pavement marking materials, at the same time achieving air purification effect (Shen *et al.*, 2012). The other coatings seem not to produce the desired result because of having more concentration of other components in the mixture such as cement than TiO_2. However, more research is required as this is still a nascent research category which still demands substantial amount of concentration to benefit the future generations to come.

4-Conclusions

This paper displays the modern research and development in the construction industry specifically concerning photocatalytic building materials and their carious applications. The scientific, laboratory and on site research avers that photocatalytic building materials are the sustainable future of a smart developing construction industry. Several photocatalytic materials have been used in various projects and the results affirm that photocatalytic materials cannot only retain the aesthetics of the building over time but it can also support well enough in making the environment free of micro-organisms. The paper also exhibits information regarding the approach to applying the photocatalytic materials such as it is discussed it detail in the case of roads which asks to keep the concentration of the mixing material in check with the TiO_2

whereas it also suggests to apply the mixture on the top of the pavement instead of mixing it inside because that would inhibit the direct reaction of TiO_2 with sunlight. Although the efficiency and durability of these materials still needs further investigation in all kinds of weathers and environment but the prospective usage of these photocatalytic building materials display massive and auspicious potential.

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A Man's World: Opening the Door for Women in Construction Management

Shelby Akers
Department of Construction Management, East Carolina University, Greenville, NC, USA
akerss16@students.ecu.edu

Amelia Saul
Department of Construction Management, East Carolina University, Greenville, NC, USA
saual12@students.ecu.edu

Syed M. Ahmed
Department of Construction Management, East Carolina University, Greenville, NC, USA
ahmeds@ecu.edu

Abstract
Women are statistically underrepresented in many project management-based industries, specifically construction management. Research on this topic often evaluates the barriers and experiences of women in the construction management field, but often does not consider roundabout ways of decreasing these barriers. Thus, the present research aimed to review the current literature regarding such barriers and experiences and considered ways to minimize such barriers as based on evidence in other industries with increasing female presence. Results from such efforts found possibilities such as considering similar areas of study, skill sets, and other field-relevant characteristics to utilize as recruiting tactics for women in the construction management field. Moving forward, the industry as a whole should aim to capitalize and recruit women as based on these various predictors of women who would do well and would be successful in the construction management industry. Recommendations and future implications are discussed in hopes of improving recruitment strategies for future generations of women in construction management.

Keywords
Women, Construction Management, Recruiting, Organizational Culture

1. Introduction

Women's presence in the workforce continues to grow in a number of industries on a global scale. Although these efforts have expanded, there is still a scarcity of women in the construction management field. In fact, the Bureau of Labor Statistics reported in 2017 that approximately

46.9% of all managers were women, but only 7.4% within the construction management field were women. The discrepancy between these two statistics brings to question why women are not as well-represented in this industry as men. Research regarding this subject matter suggests the possibility of women facing difficulties with such project management-based occupations (traditionally construction and engineering) given the “masculine” nature of the industries (Cartwright and Gale, 1995). Moreover, Cartwright and Gale (1995) found that the underrepresentation of women in construction can be largely contributed to education, training, and women’s role in society (as well as the subsequent discrimination). This poses a major threat to nearly any organization, especially for construction management given the loss of potential talent and innovation by having fewer women.

Table 1: Breakdown of Women in Construction

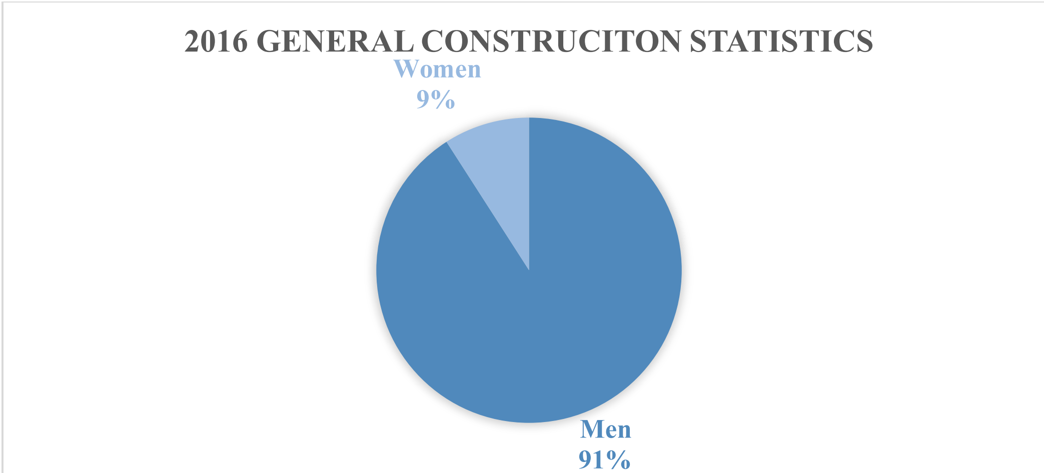
Occupation Sector	Number of Women	Percentage
Sales and Office	423,000	45%
Professional & Management	293,000	31%
Natural Resources, Construction & Maintenance	196,000	21%
Service Occupations	14,000	1.5%
Production, Transportation & Material Moving	13,000	1.4%

Source: NAWIC (2018) Retrieved from *Bureau of Labor Statistics — Current Population Survey*

Current research involving women in construction management appear to have a major focus on two major topics: 1. the barriers present that prevent women from entering the construction management sphere, and 2. the cultural experiences of women who work in construction management (e.g. behavior expectations from men, sexual harassment cases, etc.). These major subject areas are vital to the overall understanding of women in construction management, and although it is irrefutably important to investigate these matters, there continues to be a gap in the knowledge. Thus, the present paper aims to review these barriers and experiences, as well as give consideration to characteristics of the industry as they relate to other industries with healthy or growing female representation. It is believed that the identified similarities could be utilized as recruitment tactics to increase the number of women in construction management. The goal of this study is to use data gathered from various secondary datasets, official reports, and literature on the construction industry to reviews these barriers, experiences, and similar characteristics. The following sections will review the current literature of women in construction, as well as potential new angles regarding skills and characteristics present in associated fields. Findings and recommendations for recruiting tactics are also presented.

2. Literature Review of Women in Construction

As it has been mentioned, there are a number of studies and reviews that evaluate the barriers and experiences of women in construction management throughout their career stages in this field. Thus, it is beneficial to establish and recognize the precursors and cautions involved for women in the construction management field.



Source: NAWIC (2018) Retrieved from *Bureau of Labor Statistics — Current Population Survey*

Figure 1: Comparison of Male to Females in Construction

2.1. Barriers and Experiences for Women in Construction Management

The barriers women face in construction management can be summarized in three major ways: (1) sexism and masculinity associated with the industry, (2) assumed characteristics of the job, and the actual characteristics of the jobs, and (3), the lack of information and resources available to women.

Table 2: Age groupings and individual top barrier issues

	Age (years)					
	18-24	25-35	36-45	46-55	56-65	65+
Attitudes, Behavior and Perceptions	1	36	35	9	10	0
Inflexible working practices	0	11	32	13	2	0
Lack of training opportunities	2	4	15	8	12	0
Lack of support, networking and mentoring opportunities	5	17	9	4	1	0
Other Issues	1	0	3	1	0	0
Total	9	68	94	35	25	0
Sub Total						**231**

Source: Worrall, Harris, Stewart, Thomas, and McDermott (2010)

There is no secret that men dominate the construction industry worldwide. Even despite job role or profession, the male-dominated organizational culture (recognized by Harrison [1972] as power culture) and inflexible working practices stand as a major barrier to women (Worrall, Harris, Stewart, Thomas, and McDermott, 2010). Notably, women interested in construction maybe deterred from entering the field as due to fear of sexism and potential to not be seen as an equal in the eyes of their male counterparts. Moreover, not only is it a fear that this covert sexism will have an impact on the way women are perceived, but also there is a concern about being harassed either verbally, sexually or otherwise. This sexism can manifest as either overt, such as harmful sexual harassment, or subtle comments, such as calling women "baby" or "sweetie." Either way, it can still act as a major deterrent for women.

In addition to the relational components being of concern to women, so are the physical and mental. Women express concern regarding their physical strength as being a necessity for this industry, although this is often rebutted by the fact that a professional or management position within the industry does not call for the physical strength needed for labor in the field. Additionally, given the still salient status of women as primary caretakers, the concern for the lack of work-life balance and assistance in familial relations remains as a major barrier for women in construction management. Thirdly, the challenge for flexibility in work hours also creates barriers for women in their assessment of the workforce construction management has (or does not have) to offer to women.

Industry	Percentage
Human Health & Social Work	79
Education	72
Real Estate	57
Public Admin & Defense: Social Security	49
Wholesale, Retail & Car Repair	48
All Employment	46
Administrative & Support Services	44
Financial & Insurance	44
Professional, Scientific, & Technical	40
Information & Communication	29
Agriculture, Forestry & Fishing	27
Manufacturing	25
Mining, Energy & Water	20
Transport & Storage	19
Construction	12

Source: Barker (2014)

Table 3: Breakdown of Women in Each Industry

A final major set of challenges faced by women in their involvement with the construction management industry is the general lack of information and resources for women. Likely the greatest consideration is the lack of information available to women regarding construction management as a career option. Moreover, given this identified lack of women in construction management, there also stands a lack of mentorship and leadership from fellow women in the field. Because of these lacking qualities present in the construction management industry, the greatest challenge of all, perhaps, is the network of women not having knowledge about what this industry is and subsequently how to get engaged in it. If women were to break down these barriers, perhaps challenges presented above would be diminished if not resolved.

2.2. Experiences for Women in Construction Management

Gale (1994a; 1994b) conducted research regarding the perceptions of men and women in the construction industry, most notably surrounding a student sample of graduate and undergraduate women who would be entering the field. Findings revealed these women rejected feminist ties, though had contradicting concerns pertaining to the career opportunities that that would be available to them, as well as the sexism they felt they would face from their male colleagues. Moreover, the response of this student sample suggests an explicit need to behave and align one's self with that of traditionally masculine conduct, although feeling conflicted by an implicit acknowledgment that there is a chance of experiencing negative treatment for their gender.

Women tend to express an experienced shift in their behaviors to reflect that of traditionally masculine behaviors in order to minimize the possibility of acting wrongfully feminine. Additionally, some women have even reported cases where the men they were in charge of were bewildered by their presence, and thus, had to curb their leadership to coddle this perplexity. Despite feeling the need to change behaviors, there are several organizations in existence that serve to support women in construction management. Organizations of this nature include the National Association of Women in Construction (NAWIC), the Women Contractors Association (WCA), Women Construction Owners & Executive USA (WCOE), Professional Women in Construction (PWC), and Hard Hatted Women (HHW) just to name a few.

Despite these common notions about the potentially negative experiences for women in construction management, there is a slight upswing to the alterations of behavior: trust and comfortability. Although there are reports of unpleasantries associated with having to shift one's behavior, women have reported that shift to more "masculine" behaviors allow for their male coworkers and subordinates to feel more at ease and subsequently foster trust and comfortability. Doing so has been reported as helping all parties involved feel more inclusive and cohesive in tackling projects.

2.3. Valued Skills and Characteristics in for Women in Construction Management

There are several skills and characteristics in construction management, as both suggested by women and the field and research efforts, that women tend to possess that makes them especially fit for construction and project management. The major characteristics that make women strong project managers include humor, confidence, and innovation.

2.3.1. Humor

Much of human interaction and connectivity is based on humor shared. Subsequently, it is a common skillset many women in construction management recommend women to have in an effort to be successful in the field. Not only does this help to aid in gender relations among the male presence, but it also allows for a more comfortable work environment. That said, it is also recommended to maintain a zero-tolerance policy regarding the nature of the humor, as jokes and behaviors of a sexual type should not be accepted. By doing so, an appropriate balance between respect and comfortability can be made.

2.3.2. Confidence

Although confidence is a key component that nearly any working professional is recommended to have, confidence is of particular importance to women in construction management. This is tied largely to the fact that successful women in construction management are often warned about not being intimidated by those in the work environment who may try to underestimate their abilities. Moreover, it is forewarned by many women in the field to anticipate having to go the extra mile to prove skill and competency.

Many testimonies of women in the field; however, have noted that once this respect and acceptance of competency is acknowledged, any experiences of sexism tend to dissipate. Likewise, it is often noted that men (both inside and outside the construction management field) have a tendency to self-promote and show pride regarding accomplishments, whereas women have a tendency to downplay their successes. Thus, it is a valuable skillset for women to embrace their accomplishments and show similar displays of pride for achievements.

2.3.3. Innovation

One of the greatest skill a woman in construction management could have regards her ability to bring a new perspective to the table. Given that the industry has a large male presence, it is beneficial to women to have new approaches and attitudes concerning the way in which projects are handled. In fact, one such study found that women in project management director positions tend to contribute in a significantly positive way to the organization's innovative initiatives (Torchia, Calabro, Gabaldon, & Kanadli, 2018).

3. Methodology

The purpose of this study was to determine skills sets that are prevalent in industries similar to construction management with healthy or growing female representation. Information was collected via secondary data from journals in industries related to construction management (i.e. project management-related) as well as fields with a growing number of female representation (i.e. STEM careers). The data was reviewed from a meta-analytic perspective with intentions of highlighting various themes present in such literature.

4. Results

The results of the study found a variety of skills that are prevalent in industries similar to construction management with healthy or growing female representation. Such skills include being assertive, emotional intelligence, and transformational leadership. Although these skill sets are common and necessary among a number of fields and occupations, these appear to be especially prevalent in the related industries, as well as, important skills to narrow in on for recruiting women in the future.

4.1 Similar Skills for Construction Management and Female-Healthy Industries

When reviewing the literature, there are a number of skills that are widely recognized among many male-dominated industries. Some of these skills include being assertive, having emotional intelligence, and transforming leadership.

4.1.1. Be Assertive

While confidence skills are already a skill present in women of construction management, the need to be assertive is prevalent in many male-dominated industries with women making a break-through. Many anecdotes and themes of women in such fields stress the importance of keeping to one's convictions and being sure that everyone is also on board. Likewise, as it relates to project management, this also includes being assertive enough to properly delegate tasks. This is particularly important as the lack of proper delegation may lead to bottlenecks in project completion.

4.1.2. Emotional Intelligence

Although all professionals may benefit from emotional intelligence, women have a tendency to have greater emotional intelligence and empathy (Petrovici & Dobrescu, 2014). Given this notion, it would be wise to have women in a project management position and see success as this ability gives way to being able to work effectively with people. Especially in the context of construction management, often recognized by brute and bronze, there appears to be a lack of emotional substance, which may harm the industry. Subsequently, emotional intelligence has made its place in many STEM fields, and it has also shown great success. This can be further noticed in the increased number of women doing well in the STEM industries. Much like the construction management industry, many of those in such associated fields are often very science- and logic-based, which leaves little room for human emotion and feeling. Thus, it is to the benefit of women to play into their abilities towards emotional intelligence.

4.1.3. Transformational Leadership

Transformational leadership, in its nature, has a greater sense of being less authoritarian and more coaching-based. Thus, while men have a tendency to be more oriented towards being in control and having a hard hand in managing, women tend to take more of a nurturing approach to develop their leaders. Moreover, this skillset holds gravity in many management-based industries. This skill allows for even greater improvement for all those involved in the organization(s) in question as it allows for the evolution of the workforce.

5. Discussion

A participant in Gale's (1994a; 1994b) research commented on not "dragging" women and "less aggressive" men into the industry if they are uninterested, to begin with; that said, as the results of this study have shown, appeal for the project management-based industries can organically garnish if the power culture can be minimized. By doing so, the "visionary" approach (as opposed to "traditional") women bring in their management style (Vinnicombe, 1987) can help progress and transform the industry, often an asset to many businesses. Thus, as the literature and results combined may suggest, women being able to capitalize and harness skills already present for women in construction management and similar industries may boost women's status in the field.

The results of this study are important as they give insight as to what still remains constant as barriers and experiences for women work in construction management to the field. Although the participant's commentary from Gale's (1994a; 1994b) research holds some validity to not bringing in individuals into the industry against their will or interest, this is discredited by the findings that a sincere interest and care for the industry from those who traditionally do not "fit in."

That said, if the skillsets present in other women-healthy and growing female representation industries can be harnessed, the general lack of women in the field may be able to grow.

Subsequently, there has been evidence from other male-dominated industries of such skills being fostered and used in such a way that women have been able to break further into said industries. Thus, being able to market and recruit women from the perspective of the benefits of being assertive, having emotional intelligence, and being a transformational leader, all stand as a way to get women into the construction management industry. Moreover, seeing as these skills are empirically shown to be particularly prominent in women, it could be recognized that these skills can be used to recruit women based on a natural career move to make.

6. Recommendations and Conclusion

One of the greatest assets the construction management industry has for women is its narrow pay gap between men and women in the construction industry (Bureau of Labor Statistics, 2017). Thus, while this may be a way to initially grab women's attention, drawing on the results also gives attention to the fact of natural skillsets women possess that may aid their ability to be involved in the construction management industry.

In order to break down the barriers that are hindering women from joining the construction field, multiple recruitment methods need to be used. Recruitment can begin as early as elementary school when children are learning about career opportunities for the future. Instead of telling children that there are specific fields that are suited for women and others that are suited for men, teach children about multiple fields and let them decide based off their interests. But, the recruiting cannot stop there, it needs to continue through high school, college and into the workforce. In the future, the industry as a whole should aim to capitalize and recruit women based on these various predictors of women who would do well and would be successful in the construction management industry.

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Performance Evaluation of Dynamic Facades

Senem Bilir
(Asst. Prof., Istanbul Technical Univeristy, Istanbul, Turkey)
sbilir@itu.edu.tr

Mehmet Emre Bayraktar
(Prof., Istanbul Technical Univeristy, Istanbul, Turkey)
ebayraktar@itu.edu.tr

Abstract
Dynamic facades have a significant role in reducing building energy use while improving the comfort of the occupants. Also, dynamic facades can increase energy efficiency and the use of renewable energy while maintaining high levels of indoor environmental quality. This study explores advantages, disadvantages and future expectations considering the dynamic facades. The objective of this study is to gain an understanding of how experts currently define the major strengths, weaknesses, opportunities and treats of dynamic façades, key performance indicators they use and their vision for the future of dynamic facades. A qualitative study design was performed, using semi-structured interviews. Seven interviewees working in academia and practice were selected who represented the range of possible dynamic façade professionals, from researchers and designers considered performance in the assessment of dynamic facades. Our findings emphasize the challenges and the gaps for further development of effective facade control for high-performance operation of dynamic facades.

Keywords
Facade experts, semi-structured interviews, key performance indicators

1. Introduction

The main purpose of an envelope is to protect the structure and its contents from exposure to the environment effects (extreme temperatures, solar radiation, humidity, wind, rain, snow, etc.). Other considerations are generally user comfort such as acoustics, indoor air quality, etc.), aesthetics, durability, sustainability and energy performance (Moghtadernejad, 2013). During the past decade, façades are one of the most important contributing elements in reducing energy consumption. Material selection and design of façade components get more complex because of the increase in performance demands. Dynamic facades are made of different subsystems and different dynamic façade technologies and solutions have different interactions with the HVAC system, occupant comfort expectation and other building subsystems. This results into very complex systems and subsystems with very hard to predict controls and interactions. Therefore, assessment of dynamic facades has many challenges and we are willing to address those challenges and identify the gaps according to experts' opinions.

2. Scope and Method

This paper attempts to investigate the performance of dynamic facades from the view of dynamic facade experts who have minimum 6 years experiences. For this purpose, a questionnaire was prepared and seven dynamic facade experts including academicians, architects, facade subcontractors and facade consultant were interviewed.

2.1 Interview Set-Up and Background Information

Before the interviews, the authors set up a pilot study to test and improve the questionnaire's consistency. Peer reviewers were asked to comment and revise the questionnaire to provide critical feedback in order to optimize the clarity and relevance of the questions. After interviews, verbatim transcriptions were prepared, and the authors asked interviewees for approval of their answers or to include the necessary revisions.
The interview structure consisted of five main sections. In the first section, we identified the background information of the interviewees and their professional experience. In the second section, the definition and interpretation of a dynamic facade was discussed with the experts. In the third section of the interview, participants were asked about the advantages of dynamic facades. On the contrary, in section 4, the participants were asked about the perceived disadvantages of dynamic facades. Finally, in section 5, their thoughts about the future of dynamic facades were recorded.
Most of the interviewed experts represented façade engineers, façade contractors and architects. Experts were selected to cover a wide range of different actors involved in the processes of façade construction, inspection, operation and maintenance. All interviewed experts had an experience ranging from 6 to 10 years and have worked at least on one project with dynamic facades.

2.2 Interview Results

2.2.1 Definition of dynamic facades

Most interviewees associated AFs with their dynamic nature and ability to react to outdoor or indoor conditions. Solar radiation and light transmittance control were frequently mentioned as examples of useful dynamic facades' characteristics, followed by ventilation. However, no particular key performance indicator was cited when interviewees were asked how they assess the performance of a dynamic façade. Structural stability was found to be the most commonly discussed performance criterion during project commissioning and inspection.

2.2.2 Advantages and disadvantages of dynamic facades

When interviewees were asked to rank cost, energy and occupant satisfaction in order of importance for dynamic facades. The results list occupant satisfaction, cost and energy in the theoretically ideal order of importance. However, all interviewees had a different ranking about the order of importance of dynamic facades in reality. They mentioned that in real construction projects, the cost is considered to be the most important variable followed by energy and finally occupant satisfaction. For most projects they participated in, there was no feedback loop regarding occupant satisfaction. Only few interviewees had been involved in a soft-landing stage and performed post-occupancy evaluation for their designed and constructed dynamic facades.

The strengths of dynamic facades involved providing dynamic operation for optimal daylighting, solar control and natural ventilation and the optimization of heating and cooling loads. Also, interviewees identified the empowerment of users to control the indoor climate as a powerful benefit leading to higher occupant satisfaction and productivity. In parallel, there is an opportunity to increase dynamic facades in the market due to mass customization and the advancement of building controls. On the other hand, the high investment cost and the need for tailor-made solutions for dynamic facades were identified as weaknesses. The largest risk associated with dynamic facades was the operational and construction stage and the weak management of the maintenance and long-term performance and occupant control.

2.2.3 Dynamic characteristics of the projects

Interviewees were asked that the dynamic characteristics in their projects. According to the answers there are various dynamic project characteristics, such as operable windows, shadings, wind speed and water sensor, light transmittance as well as ventilation systems (Figure 1).

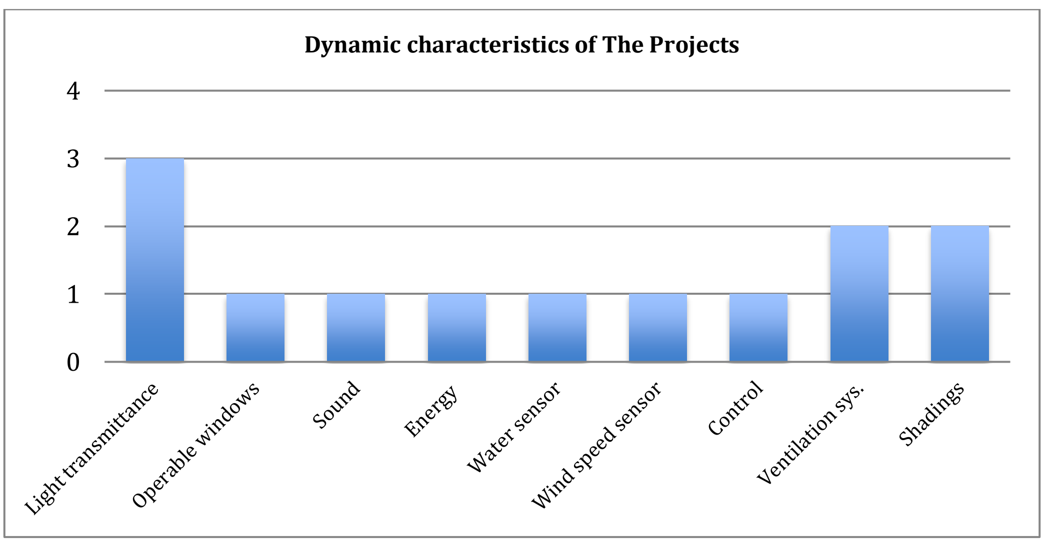

Figure 1. Dynamic characteristics in the projects

2.2.4 Key performance indicators of dynamic facades

Authors asked the interviewees the key performance indicators that they use in the performance assessment of dynamic facades and some of the answer were stability and robustness, water and air tightness, annual energy consumption, performance of structure, interaction between components as shown in Figure 2.

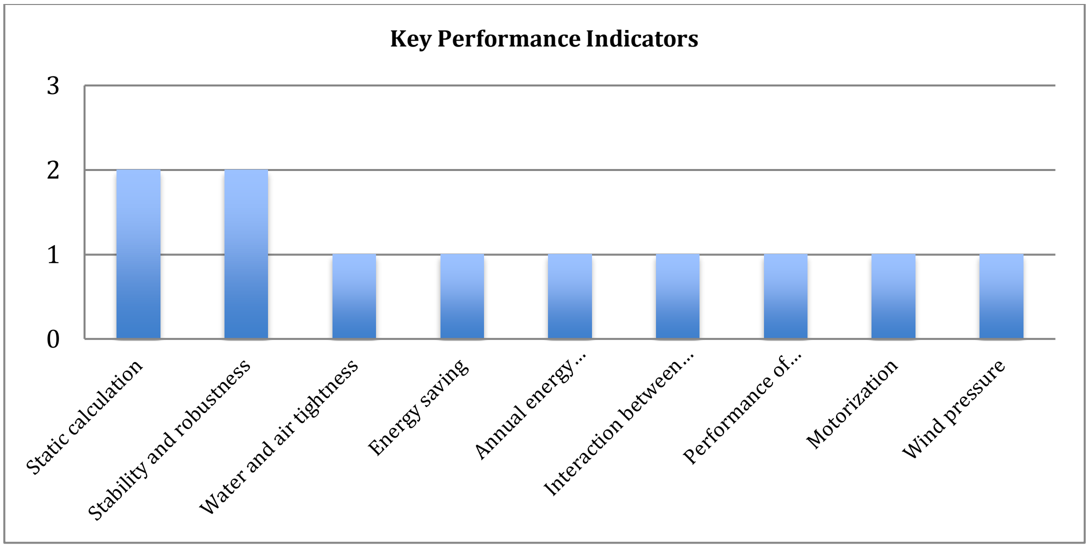

Figure 2. Key performance indicators in the projects

2.2.5 Future of dynamic facades

Interviewees described their expectations and future ideas that dynamic facades should integrate. Three major questions shaped the responses and are structured under the following paragraphs:

What needs to be done for a better dynamic façades' design process and performance quality?

- Develop a framework of KPIs that are user-centric and that address occupants' well-being and productivity in relation to dynamic facades.
- Determine universal user satisfaction indicators and standards and associate them with dynamic facades environmental performance.
- Develop better tools to predict AF performance while taking into account users and their behavioral variability and the dynamic nature of the facades.

What features would you expect to find in future dynamic facades?

- User-driven façade technologies using smartphones or individualized preset occupant operation preferences.
- Real-time personalized and individualized control.
- Intelligent feedback mechanisms to visualize outdoor and indoor conditions in real-time.

Who should be responsible for maintaining the dynamic façade performance after construction?

- Performance contracts can be used to maintain the performance of AFs as part of the whole building level performance.
- By developing holistic guarantees for AFs' maintenance, operation and continuous commissioning, it will become a common practice resulting in a robust facade performance.

3. Conclusions

The aim of the study was to analyze the expert opinions in order to identify the gaps in dynamic facades performance. The methodology used in the study was based on semi-structured interviews. The interviewed experts could not form a statistically representative sample.

However, they provide a snapshot that was elaborated on by the authors in terms of current challenges in dynamic facades performance assessment.

Dynamic facades must function in relation to occupant comfort and different KPIs. Product-based facades should be designed, constructed and operated as integrated systems. Quality assurance and holistic assessment can only be guaranteed by long-term monitoring and by coupling performance to their operations. The authors are expecting that the assessment of dynamic facades and performance evaluation will increase its market penetration. However, this needs to be coupled to mass customization and personalized occupant control. Smart and predictive maintenance can assure dynamic facades robust performance and their liability.

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Protection of urban areas during repair work, structure demolition, and construction

Mehmet Emre Bayraktar
Professor, Istanbul Technical University, Istanbul, Turkey

Farrukh Arif
Associate Professor, NED University of Engineering & Technology, Karachi, Pakistan

Abstract
Focusing on recent practices, this paper introduces urban protection tools that are available in the construction industry. Over the course of the research, the current state of practice was determined based through a questionnaire and an interview survey which included nationwide general contractor companies and the project executive of a safety management company located in South Florida, respectively. The study showed that there are five tools which are most commonly used in construction practices including Hand Rails with Toe boards, Overhead/Walkway Canopy, Outrigger Debris Containment Netting System, Canopy Netting System, and Vertical Netting System (Cocoon System).

Keywords
Safety, construction site management, urban protection during construction

1. Introduction

High rise buildings have become a trend nowadays due to their economical, architectural and territorial advantages. Largest cities of the world are competing with each other in the unwritten contest for the highest building. Architectural agencies develop projects – one more intricate than another – every day, but with this "Build the Tallest Building" rush one could easily forget of one of the most important parts of the construction process – safety and protection of surroundings.

What to protect during high rise construction and reconstruction? Firstly and most importantly – pedestrian. Construction sites often may create unsafe conditions for workers of the site, visitors, and of course, pedestrians. Each year, about 100 pedestrians are killed in the United States due to construction site accidents in addition to many more people who are seriously injured. Some of the most severe injuries, and even fatalities most of the time are a result of falling objects or debris. The most common objects that may come loose are handheld tools, loose pieces of masonry, and other materials. Typically, injuries made to pedestrians are caused by events where pedestrians walk directly in front of the site, or they are too close to the work zone due to lack of barricading, when they obtain unauthorized access to the site, or visit the site without any proper attire (Bellottilaw 2018).

Often injuries are caused by the lack of safety precautions. Construction companies and site owners are obligated to provide safe means of passing to all citizens, and vehicles. When such precautions are not taken, the construction site becomes a zone of danger, and all the injuries around the site are caused by the negligence of operating parties (Bellottilaw 2018). The most commonly seen examples of negligence are failure to use access limiting barricades, post warning signs at construction sites, and failure to adequately secure construction sites (including watchmen and/or locking sites at night hours). Often it is a failure to use safety tools and devices when needed to prevent falling objects and debris (among such debris nets, toe boards and catch platforms).

Another important part of the urban landscape that needs a thorough protection is historical buildings. Valued for the ability to survive through time historical buildings need help to survive ever-changing present. Whether it is a reconstruction and remodeling of a nearby building, demolition of an existing structure, or a new high rise construction site, damage made to the shorter historical building could be permanent. It is a responsibility of both, the owner of the historical building, and the new construction site developer, to take a careful consideration of any potential damages could be made, and take necessary precautions. Early planning and control of the process could be of a great help to successfully avoid damages. Not only falling objects, but damage by dust, improper machinery operation, vibrations, fire, and water should be prevented. These issues are often overlooked during the construction process, when the project is undertaken.

What else to protect? Parking lots, existing shorter buildings, lakes, ponds and reservoirs, electrical wiring, trees, landscape, and vegetation - everything around the construction zone is potentially endangered by the process.

2. Review of Standards and Requirements

Main requirements for urban protection in construction zones are described by Occupational Safety and Health Administration (OSHA), and American National Standards Institute (ANSI). OSHA is part of the United States Department of Labor, created by Congress with the Occupational Safety and Health Act of 1970. According to OSHA requirements construction site owners must provide safe working conditions for both, workers and pedestrian traffic, and examine workplace conditions to make sure they conform to applicable OSHA standards (SGEIS 2011).

The following protection standards are applicable to nowadays construction processes. In every building or structure shall be so arranged and maintained as to provide free and unobstructed egress from all parts of the building or structure at all times when it is occupied. 1926.34 - Means of egress. Danger signs shall be used only where an immediate hazard exists, and shall follow the specifications illustrated in Figure 1 of ANSI Z35.1-1968 or in Figures 1 to 13 of ANSI Z535.2-2011, incorporated by reference in § 1926.6. Signaling by flaggers and the use of flaggers, including warning garments worn by flaggers, shall conform to Part VI of the Manual on Uniform Traffic Control Devices (1988 Edition, Revision 3, or the Millennium Edition), incorporated by reference in Sec. 1926.6. 1926.201 – Signaling (CFR 2018, OSHA 2018).

Safety nets must be installed as close as practicable under the surface on which employees are working, but in no case more than 30 feet below (Oshatrain 2018). When nets are used on bridges, the potential fall area must be unobstructed. As indicated in Oshatrain (2018), safety nets and safety net installations must be drop-tested at the jobsite including after initial installation and before being used, whenever relocated, after major repair, and at 6-month intervals if left in one place.

3. Research Methodology

In order to determine current state of practice the author has used following tools of research:

- Created a small questionnaire for construction managers on site;
- Conducted an interview with the manager of a safety subcontractor in South Florida;

Below is the questionnaire for construction managers of 10 nationwide construction companies, with the most popular answers marked bold. This tool has helped identify the current situation in the field:

1. The company I work for has a strong safety and urban protection policy.

   Strongly disagree | Disagree | Not Sure | ***Agree*** | Strongly Agree

2. Safety and urban protection is a priority when determining the construction work budget.

   Strongly disagree | ***Disagree*** | Not Sure | Agree | Strongly Agree

3. What are the most commonly used protection tools are implemented within the company I work for?

   Netting systems | Overhead / walkway | Man power (flaggers) | No protection used

The next step in the research included an interview with the manager of a safety subcontractor company in South Florida.

Q 1. What are the major aspects do safety managers analyze when creating a safety plan?

A.: The answer included the following aspects:

a) how close are pedestrian walkways to the construction site, and how busy are those during day and night hours;

b) whether or not there is a public transportation line passing by the site, this aspect increases the heaviness of pedestrian traffic;

c) whether or not the building will be used during construction/repair work (pools, amenity decks, etc.)

d) whether or not there are existing shorter buildings surrounding the site, which could potentially get damaged or destroyed.

Q 2. What are the most common incidents, which occur during construction? What is the most current incident occurred?

A.: Struck by falling objects (debris). Piece of heavy lumber has fallen off of 48^{th} level, luckily hasn't injured anyone.

Q 3. How tall does a projected building have to be in order to require urban protection plan?

A.: 2 stories and up.

Q 4. What is the percentage of sites using nowadays safety and protection tools?

A.: 8 out of 10

Q 5. What are the most commonly used protection tools used?

A.: Outrigger and Canopy debris containment netting systems, walkway overhead protection, flaggers (manpower).

Q 6. What percentage of safety plans dedicated to urban protection?

A.: Approximately 70%

Q 7. Is there any classification of levels of protection commonly used?

A.: Yes, low level 1-2 tools, medium level 3-5, high level 6 and up.

4. Current State-of-Practice

After careful analysis the authors determined the main tools to avoid injury or damages from falling objects that are currently used in construction operations:

1. Handrail (Figure 1)
   By OSHA handrails to be constructed of top rail, mid rail, and toe board with mesh net to prevent items being kicked off the edge of platforms. Hand rails with toe boards are the most commonly used tool, as besides protecting from falling object, it serves as a safety fall protection for construction employees.

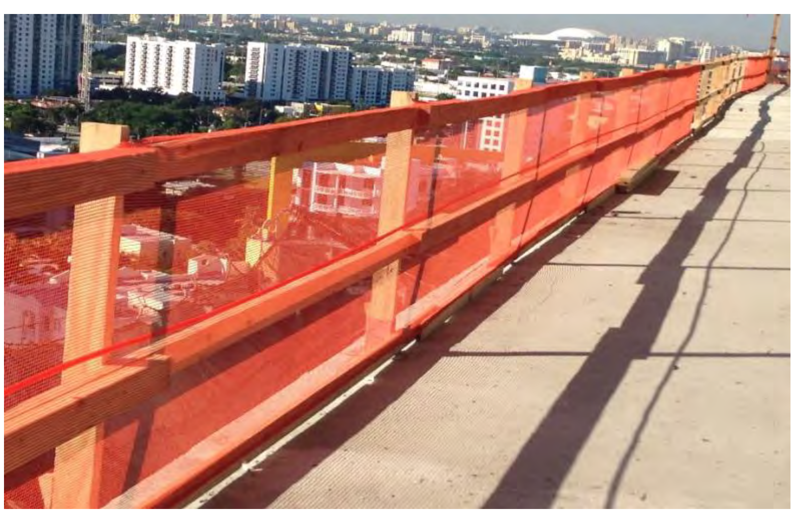

Figure 1: Handrail

2. <u>Overhead/Walkway Canopy (Figure 2)</u>
    - Allows safe pedestrian walkway path along construction sites;
    - Preventing injuries from falling objects (debris, materials, tools);
    - OSHA requires canopies to be of a certain width and height.

3. <u>Outrigger Debris Containment Netting System (Figure 3)</u> - connected the slab edge to help prevent materials that come loose during the working deck pouring, cleaning, stripping operations from falling to the ground (CFR 2018).
    - Drilled or clamped to slab edge;
    - No more than 30 feet (9.1 m) below working deck (OSHA 1926.502(c)(1))
    - Installed with sufficient clearance under them to prevent contact with the surface (OSHA 1926.502(c)(3)

Figure 2: Overhead/Walkway Canopy

Figure 3: Outrigger Debris Containment Netting System

4. Vertical Netting System (Cocoon System) (Figure 4)

- Increase safety by preventing debris from falling on the public and adjacent properties below;
- Installed 6’ away to allow work in swing stages;
- Bottom part of net is folded to create a “catching bag”

5. Canopy Netting System (Figure 5)

- Used to cover objects located below working deck in radius of 20 feet;
- Double netting (liners, cargo nets)
- Liners replaced periodically;
- Installed with sufficient clearance under them to prevent contact with the surface (CFR 2018)

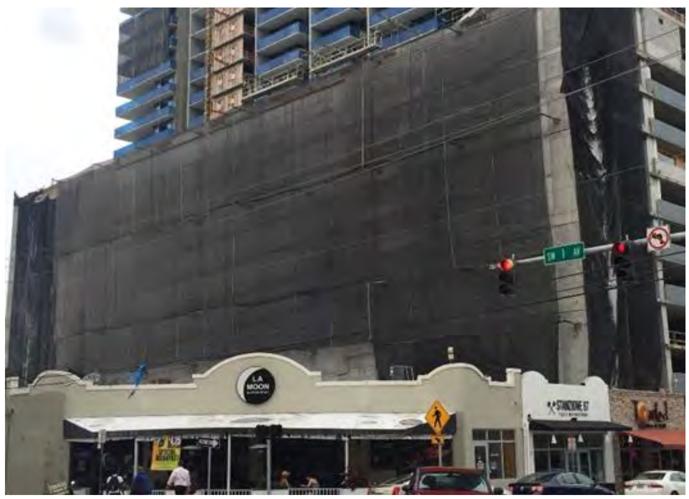

Figure 4: Vertical Netting System

Figure 5: Canopy Netting System

5. Conclusions

This paper studied urban protection tools that are available in the construction industry. The current state of practice was determined based on a questionnaire and interview survey which included nationwide general contractor companies and the project executive of a safety management company located in South Florida. The study showed that there are five tools which are most commonly used in construction practices including Hand Rails with Toe boards, Overhead/Walkway Canopy, Outrigger Debris Containment Netting System, Canopy Netting System, and Vertical Netting System (Cocoon System). Based on the questionnaire survey, the construction companies seemed to have a strong safety and urban protection policy. However, safety and urban protection was not a priority when determining the construction work budget.

6. References

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