EDUCATING BUILDING PROFESSIONALS FOR THE FUTURE IN THE GLOBALISED WORLD

TECHNOLOGY

VOLUME 2

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Associate Professor Monty Sutrisna
Dr Ahmed Hammad
Dr Chamila Ramanayaka
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Full papers accepted for publishing in the Conference Proceedings are subject to a blind peer review process. The 2018 Conference Committee gratefully acknowledges the generous work of the reviewers, who provide constructive and invaluable feedback within tight time frames to ensure the high standard of published papers. A full list of scientific committee is published on page x.
PREFACE

It is a great pleasure to write a preface to this volume on the technology stream of the 42nd AUBEA 2018 Conference proceeding. Throughout the long history from its formation in 1975, AUBEA has been convening annual conferences successfully. This 42nd AUBEA conference, however, is the first AUBEA conference held in the Asia region. This represents the recognition of the significant roles played by the Asian region in the global building industry and building education. As soon as we received the mandate to host this conference, the organising committee immediately considered Singapore as a potential venue for the conference. Singapore as a place has inspired us to anticipate the theme of this conference as: “Educating Building Professionals for the Future: Innovation, Technology and Sustainability in the Globalised Market.” The theme embodies the characteristics, challenges and opportunities facing the building education sector at the current time and beyond. We all know that the very nature of our building education sector calls for in-depth collaboration between industry and academia to educate building professionals fit for the future. Industry and academia are shaping the future of the profession together and it is highly celebrated in this conference through the selection of the prominent keynote and stream experts, as well as the highly interactive conference programme.

I would like to take this opportunity to show my gratitude to my colleagues in the organising committee who have been working very hard to make this conference a reality. On behalf of the organising committee, I would also like to thank the AUBEA Council for entrusting us with the mandate to host the conference and also to show appreciation to the sponsors and partners of this conference that has supported the conference. We also would like to acknowledge the important contribution from the scientific reviewers who have been generously devoting their time to review abstracts and full papers submitted to this conference to ensure the quality of the papers accepted, as well as the session chairs who are instrumental to the success of the delivery of the paper presentation sessions.

Last but not least, it is our aim to recognise excellence. Therefore, the organising committee have also set up various scholarships and awards in this conference. We have set up the AUBEA 2018 conference to provide a conducive environment and a platform for industry and academia to further collaborate in educating building professionals for the future. On behalf of the organising committee I would like to thank delegates for joining us in this celebration of learning and participating in this exciting conference.

FOREWORD FROM THE CHAIR

It is with great delight I am writing this introduction for AUBEA 2018 Conference proceedings. Throughout the long history from its formation in 1975, AUBEA has been convening annual conferences successfully. This 42nd AUBEA conference, however, is the first AUBEA conference held in the Asia region. This represents the recognition of the significant roles played by the Asian region in the global building industry and building education. As soon as we received the mandate to host this conference, the organising committee immediately considered Singapore as a potential venue for the conference. Singapore as a place has inspired us to anticipate the theme of this conference as: “Educating Building Professionals for the Future: Innovation, Technology and Sustainability in the Globalised Market.” The theme embodies the characteristics, challenges and opportunities facing the building education sector at the current time and beyond. We all know that the very nature of our building education sector calls for in-depth collaboration between industry and academia to educate building professionals fit for the future. Industry and academia are shaping the future of the profession together and it is highly celebrated in this conference through the selection of the prominent keynote and stream experts, as well as the highly interactive conference programme.

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The overarching theme of the 2018 AUBEA Conference is "Educating Building Professionals for the Future in the Globalised World" in recognition of the multiple and complex demands placed on assessment in higher education. Some of these challenges are long-standing, such as those relating to continuously synchronising education and industry practice. Other challenges are emerging as national priorities, funding arrangements and policy frameworks change.

The THREE streams:

1. Innovation
2. Technology
3. Sustainability

**CONFERENCE THEMES**

**Educating Building Professional for the Future in the Globalised World**

The breadth of the papers presented is wide covering a vast array of subjects that pivot around the central theme of innovation. Performance in any industry is important and none more so than the construction industry, where none performance can come with high liquidated damages. One paper looks at the effect of cultural diversity on project performance, with a focus on its contribution to project success. On a similar theme of culture, the re-purposing of surveillance cameras is investigated, with the suggestion that they may be used to support urban densification in a sustainable way. The push for the densification of our cities cannot happen if the cost of construction is high, this then poses a challenge to industry to perform at an exceptional level, permitting the dynamics of an evolving industry to be rapidly transferred to its key players.

In the context of the built environment, technology plays a significant role in defining the overall systems that are opening new avenues in integration of the built and human environments. From real-time data that is instantly generated, and which enables constant analysis of implemented strategies, to the use of artificial intelligence to automate essential functions within the built environment through enhanced pattern recognition.

The 42nd Australasian Universities Building Education Association (AUBEA) Conference aims to showcase the novel approaches that are implemented for integrating technology within the built environment, with focus on its adoption to further enhance the education of professionals in the field. It is through exhibiting and sharing of the most recent advances in technology integration within the built environment that we envisage an enhanced sector that is capable of bridging human behaviour with its surrounding built environment worldwide. The "technology stream" of AUBEA this year hence provides a pivotal exploration and deep insight into future applications of intelligent technology in the built environment, helping to further ignite the adoption of effective technology within the field. Please join us for this unique experience in Singapore!

In its broadest terms, the definition of 'sustainability' has been in a perpetual state of refinement since its inception some 40 years ago. It is generally accepted to be the ability to preserve, sustain and balance healthy environmental, economic and social systems, on an international scale. Next to this, exponential population growth and shifts to urban environments necessitates a sustainably-responsible demand for construction and densification of cities. Construction has the capacity to make a critical impact on global sustainability agenda given that buildings in the first world contribute to more than forty percent of the energy consumption over their lifetime. When we consider production of raw materials, construction, operation, maintenance and decommissioning—densification and as a consequence—construction (of cities) provides significant opportunities for sustainable development of built environments and infrastructure.

Throughout history, the creativity and capacity of people's imagination have been main drivers in the theorisation of technology implemented in our daily lives. In today's age, technology integration within the built environment has reached a highly influential level that shapes the overall interaction of people with buildings that are surrounding them. Technology has also meant that the capacity for educating building professionals for the future has advanced to an exceptional level, permitting the dynamics of an evolving industry to be rapidly transferred to its key players.

The 42nd AUBEA Conference aims to showcase the novel approaches that are implemented for integrating technology within the built environment, with focus on its adoption to further enhance the education of professionals in the field. It is through exhibiting and sharing of the most recent advances in technology integration within the built environment that we envisage an enhanced sector that is capable of bridging human behaviour with its surrounding built environment worldwide. The "technology stream" of AUBEA this year hence provides a pivotal exploration and deep insight into future applications of intelligent technology in the built environment, helping to further ignite the adoption of effective technology within the field. Please join us for this unique experience in Singapore!
This section contains the abstracts and full papers presented at the conference. On behalf of the conference committee, we would like to acknowledge and thank the delegates that submitted papers for consideration under the conference themes of Innovation, Technology and Sustainability. Table 1 below shows the number of submissions and outcomes in each category.

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<th>Submission Format</th>
<th>Abstracts Received</th>
<th>Full Papers Received</th>
<th>Final outcomes (total)</th>
</tr>
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<tr>
<td>Papers (Innovation)</td>
<td>46</td>
<td>36</td>
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<td>Papers (Technology)</td>
<td>26</td>
<td>31</td>
<td>28</td>
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<tr>
<td>Papers (Sustainability)</td>
<td>30</td>
<td>35</td>
<td>34</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>102</td>
<td>89</td>
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</tbody>
</table>

Full papers identified as ‘Full Paper – Peer Reviewed’ in the Conference Proceedings have undergone a blind peer review process, with de-identified feedback and suggestions for revisions provided to authors. All submissions were also reviewed by members of the conference committee review panel. We gratefully acknowledge the generous work of the reviewers, a national and international group of colleagues who contributed their time and expertise to provide review commentary, including constructive and valuable feedback for all submissions.

These proceedings are published by Curtin University under ISBN 978-0-9871831-4-9 (Print) & ISBN 978-0-9871831-7-0 (e-Book). We hope that this collection of papers will make a positive contribution to the ongoing discussion about those challenging issues that lie at the heart of assessment.

Disclaimer

The papers published in this Conference Program have been reviewed, edited and proofread to the best of our ability within the timeframe permitted. We acknowledge that there may be further proofing errors.

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Proposing an integrated model for assessing project performance under risky conditions utilising learning curve

Loza Ahmadi and Monty Sutrisna

Abstract:
In Project Management field, performance assessment has become one of the increasingly popular research area. It has been considered crucial to measure and optimise project’s performance. Among various performance assessment models, Earned Value Management (EVM) is a recognised technique for managing and evaluating performance. Recent evidence suggests that project performance is affected by how uncertainties are managed and how lessons learnt from prior experiences in delivering the project have been utilised to continue managing the project effectively. However, EVM was not originally developed to model uncertainty and incorporate learning and hence it has received criticisms regarding its ability to estimate the project future performance. As construction projects (CPs) can be considered knowledge based projects, effective capture of lessons learnt, knowledge and experience are critical factors in CPs as they can directly impact on project delivery, project management ‘triangle’ and team work performance. Therefore, knowledge management (KM) is an effective approach for enhancing CP performance. Given that knowledge creation is a crucial part of the KM, considering this theory which arises in every CP stages especially throughout the earlier phases can be recommended. This paper aims to review and summarise the role of knowledge creation in project stages in terms of effectiveness in project performance. Thus, taking into account construction project classifications, PM knowledge can improve performance and balance the competing project’s expectation. In general, as construction projects are typically classified as containing high level of risks, they require continuous monitoring for effective project control (Ezeldin and Sharara, 2006). It has been indicated that the capture of knowledge in the forms of backgrounds and experiences, training and learning are important factors in achieving the performance targets of these knowledge-based projects (Ahmadi and Sutrisna, 2018). The risks of cost and time overruns have greatly impacted the construction sector mainly due to the lower level of performance stemming from the lack of capturing learning from previous experiences in dealing with the risks in the construction operations (Zeng et al., 2007). This research indicated that traditional delivery techniques typically fail to take into account the learning effects in these projects (Walworth et al., 2016). Therefore, in performance assessment, learning curve is considered essential (Ugwa et al., 2006) to be developed meaningfully through the lesson learned from previous experiences (Blindenbach-Driessen et al., 2010).

This study is organised as follows: the next section is a review and classification of the performance measurement techniques in the construction sector. The approach method, their potentials and effective factors for improving construction project performance are also highlighted. Then, the role of knowledge creation in project stages in terms of effectiveness in project performance are discussed. Final concluding remarks consider to highlight the main features affecting the construction project performance.

2 Project Performance Measurement

Achieving project success largely depends on its performance objectives, including time, cost and quality. One of the main reasons for poor performance in CPs is the high-risk involved in their execution, hence the need to intensively monitor/asses performance (Clough et al., 2005). There are some techniques to assess the performance. Among them, the Earned Value management (EVM) has been known as an effective method with the capability of predicting costs and duration as well as tracking a project progress (Alvarado et al., 2004). Some studies also argued that EVM is the ‘best’ quantitative model for evaluating and controlling the contractors’ performance. Hence, it can be used as the methodology for assessing project performance (Anbari, 2003). EVM integrates planning and cost indices into the project scope and can be used to form a baseline for project performance measurement (PMM). Subsequently, EVM has become a standard in the construction industry to measure project performance during the execution phase (Batselier and Vanhoucke, 2017). It is mainly because EVM provides a dashboard management system of performance measures for evaluating single or multiple projects. It is a method of creating project-specific progress curves based on past data and ongoing situations. However, as presented in Table 1, most of the traditional techniques do not take into account the learning effects despite the fact that learning has been recognised as an essential element of any project (Walworth et al., 2016). Also, a number of studies have shown that the Learning Curve (LC) is a suitable tool to model the dynamic behaviour of the contractor’s performance (Jordan et al., 2015; Lee et al., 2015; Wong et al., 2007). Different PM methods are reviewed and summarised in the Table 1 below.
Table 1. The classification of the performance measurement models in construction industry

<table>
<thead>
<tr>
<th>Reference</th>
<th>Model</th>
<th>Performance indicators</th>
<th>Approach method</th>
<th>Performance prediction</th>
<th>Country</th>
<th>Learning effects</th>
<th>Case study</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Budescu et al., 2004)</td>
<td>KPI, Balanced Scorecard</td>
<td>BSC’s views - Concentration costs, Safety, time, Quality, Predictability, Productivity</td>
<td>review the main performance measurement frameworks</td>
<td>-</td>
<td>U.K.</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Chan and Chan, 2004)</td>
<td>KPI</td>
<td>Construction time, Time variation, Health and Environmental performance, Functionality Satisfied</td>
<td>multi-disciplinary approach</td>
<td>-</td>
<td>Hong Kong</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Shahadat et al., 2007)</td>
<td>KPI</td>
<td>Cost, profit, Labour utilisation</td>
<td>action research</td>
<td>-</td>
<td>Scotland</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Alsour et al., 2013)</td>
<td>KPI</td>
<td>Environmental, social, economic and technological elements</td>
<td>multi-attribute approach</td>
<td>-</td>
<td>UK</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Alsour and Benedict, 2011)</td>
<td>A conceptual framework</td>
<td>Post-triment related success items</td>
<td>Structural equation modelling (SEM)</td>
<td>-</td>
<td>UK</td>
<td>-</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Alsour and Bader, 2013)</td>
<td>lean thinking</td>
<td>Construction wastes, Lean Planner, Scrum techniques</td>
<td>-</td>
<td>-</td>
<td>Egypt</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Melayu et al., 2013)</td>
<td>LC</td>
<td>Time and cost, Learning curve prediction model</td>
<td>✓</td>
<td>-</td>
<td>Hungary</td>
<td>✓</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Kim, 2015)</td>
<td>EVM</td>
<td>CV, Performance Stability</td>
<td>Incremental cost-benefit analytical model</td>
<td>✓</td>
<td>US</td>
<td>✓</td>
<td>✓</td>
<td>-</td>
</tr>
<tr>
<td>(Wadagoodarpitya et al., 2016)</td>
<td>-</td>
<td>Multidimensional model (BSC, AHP, MP and KPI)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Rahman and Stanke, 2016)</td>
<td>EVM and ANP</td>
<td>Multi-criteria decision making (MCDM)</td>
<td>✓</td>
<td>-</td>
<td>Taiwan</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Present study</td>
<td>EVM and LC</td>
<td>Time and cost estimated at completion</td>
<td>✓</td>
<td>-</td>
<td>Iran</td>
<td>✓</td>
<td>✓</td>
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</table>

Project performance is affected by certain elements such as risk conditions, background, financial capability and resources availability. It is recognised by Dyer and Singh (1998) that learning helps sectors to get higher performance through project process and construction industry requires various skills to establish learning base for advanced changes in order to increase efficiency. On the other hand, experienced teams have different knowledge and lesson learnt from prior projects to deal with risk, complexity and challenges (Langford, 1996). Thus, learning is accepted as a specific and effective experience accumulation to create a unique setting and construction sector needs this setting to achieve continuous improvement to enhance performance (Langford, 1996). Further, lesson learnt contains various project aspects and it can be incorporated in the project management to reduce consequences of risks as an effective factor. Focusing on learning from lessons databases, can be a part of risk mitigation to overcome the project challenges and decrease uncertainties (Dikmen, 2008). Malyusz and Varga (2016) proposed an estimation model on the basis of a LC for project scheduling. The learning effect was applied to critical path method (CPM) and an effective solution method was proposed to obtain an accurate estimate of the project duration. LC theory is considered a practical tool for planning and predicting human resource behaviour (Jaber, 2016). Despite the widespread use of learning models, this theory has not been extensively implemented in the evaluation process (Paras and Pantouvakiotis, 2017). Whilst the research carried out so far significantly focused in the field of project performance is on identification and assessment of risk, there are very few studies of performance prediction combining risk and learning. Kim (2010) proposed a framework for risk and performance assessment based on EVM for mega infrastructure projects. The designed model has been utilised to elaborate the adaptability of the traditional performance assessments and the project performance model was extended by incorporation of the risk factors into the schedule and cost performance indexes (SPI and CPI). Regarding contracting and how it can support the risk allocation decisions, Bak et al., (2012) designed an innovative approach for the quantification of project risk of Engineer Procure Construct (EPC) contracts. Different risk factors e.g. contractual risks have been identified in construction projects that affect CPI and SPI. A risk management strategy based on Risk Breakdown Structure (RBS) was adopted. The proposed risk assessment framework enables the decision maker to design mitigation plans via a proactive management system. These two, however, have not combined risks and learning. This research, therefore, aims to fill this gap by integrating risks and learning in developing a more robust performance assessment.

Following the on-going discussion, it has been established that project performance can be significantly affected by the process of learning and knowledge transfer (Karlsen and Gottschalk, 2004). Many studies have focused on the PM but only a few have analyzed the learning effect and risk simultaneously (Jimenez-Jimenez and Sanz-Valle, 2011) and hence understanding the learning effect as a key in achieving a successful project delivery (Ellis and Spielberg, 2003). An intended model is envisaged to be able to capable of capturing the future scenarios for project cost at completion allowing for uncertainty conditions. The proposed integrated framework based on EVM and risk analysis is expected to reduce deviations in time and cost at completion. Risk performance index has been obtained by bootstrap resampling techniques (Denas, 2015). The result of experiments demonstrated that more accurate estimations of the final cost and time with higher confidence levels can be obtained. The outcomes of a real case study specify that more accurate estimates at the competition (EAC) are obtainable by these enhanced approaches as opposed to the traditional approaches. A more accurate project baseline will enhance the project’s performance management. Newly integrated project performance assessment methods are needed that also take into account the learning for predicting the project future status in terms of risks and performance. Because, the performance assessment is important to control the project activities effectively and avoid repetitive errors (Blindenburg-Driessen et al., 2010). So far, the main limitations can be summarised:

- Assessments limited to static conditions (e.g. linear performance of the human resources) that are no longer applicable in the increasingly complex projects.
- Change in the performance as a result of the occurrence of a risk situation related to one or more activities of the project.
• The application of learning functions that are able to reduce the impact of risks as well as to improve EVM prediction power, both in the planning stage and during the execution.

Thus, the first step will be to review the PM tools to increase project performance. For achieving this stage, understanding the risks involved and current practices in measuring performance, particularly using EVM, establishing possible ways for integrating learning to improve the management of risks, effective knowledge and developing an analytical tool to advance the existing EVM tools to support an effective performance management in pre-construction projects phases are main objectives to support and continue this research for developing the framework.

3 Construction Projects as Knowledge Creation: A Fresh Perspective

It is acknowledged that construction sector is increasingly regarded as a knowledge-based sector (Desouza and Evaristo, 2006). Most projects including but not limited to R&D and innovative projects require combined knowledge and experience (Laurent and Burtischell, 2017). As this sector is becoming increasingly global (Ngowi et al., 2005), there is a significant potential to cross learn and to increase performance. To do this, learning advanced design, new concept, innovative construction technology and materials are needed, particularly in project earlier stages (Laurent and Burtischell, 2017). Although such knowledge is critical in all project stages to achieve the schedule and budget targets, it is argued here that there is value in focusing on obtaining these knowledge in the front-end of a construction project if successful delivery is to be achieved. Therefore, this research subsequently focuses on knowledge management as the underpinning perspective to facilitate the knowledge creation during the front-end stages of construction projects. KM is generally identified as a practice and systematic attempt to create, achieve, share and use knowledge to improve performance (Scarbrough et al., 1999).

From Knowledge Management (KM) perspective, Egbu (2002) presented KM as an effective influence in construction sector efficiency and have a potential to produce benefits to this industry, highlighting KM as the important platform to create new technologies, innovate new concept and benefit the projects. It has been argued that knowledge is the main asset in order to consider and deal with innovation and constant improvement in projects (Scarbrough et al., 1999). According to Blackler et al., (1998) this aspect is a fundamental success factor for achieving improvement in an organisation. Further, Nonaka and Takeuchi (1995) argue that knowledge is an essential recourse for a system. Therefore, the role of KM in creating improvement in the construction process is really important (Mehralian et al., 2018).

It has been acknowledged that KM has a lifecycle which involves some process and there are some similarities in its definition (Mehralian et al., 2018). For example, Bhatt (2001) argued that KM process includes knowledge creation, knowledge validation, knowledge presentation, knowledge distribution and knowledge application. Regardless of how KM is outlined, knowledge creation (KC) process is a crucial stage in KM (Mehralian et al., 2018). Also, KC is an important process to develop the organisation ability for producing useful solutions and creating various idea (Bhatt 2001). In terms of construction projects, KC is considered as a constant procedure through which the knowledge created by the project team becomes achievable in the project and it supports the system capabilities for continues improvement (Von Krogh et al., 2012). The KC theory was first presented by Nonaka and involved of four characteristic relations between tacit and explicit knowledge.

...
learning from captured previous experience) is the combination procedure to create an organised and more efficient explicit knowledge to be able to perform the project. This new knowledge platform is then shared throughout the project team. As in the process in construction stages, each phase of the KC is to change and advance from the knowledge creation procedure to a new cycle of KC at a various level of reasoning. With this “spiral procedure”, the new knowledge needs to be shared and established in the projects to enable further cycle of KC to take place.

4 The Proposed Research Methodology

Research methodology envisaged for this research can be summarised in the Figure 3 below. It focuses on the knowledge in CPs where the risk factors and learning rate have significant impacts on performance (Alhawari, 2012). The research concept bases can be generally divided into three groups: (1) PPM techniques and tools including the EVM, (2) risk modelling and (3) LC modelling. The integration of these groups provide a theoretical basis for designing the integrated performance management tools in CPs. And, it comprises the following steps:

- Exploring existing PPM methods applied and mapping knowledge in CPs including their advantages and disadvantages. This involves the data collection and analysis from the projects. Further data analysis involve applying statistical techniques (Motulsky and Christopoulos, 2004), operating characteristics and goodness-of-fit test (Montgomery et al., 2009).
- Exploring existing body of knowledge in risks and their modellign techniques.
- Exploring existing body of knowledge in LC and their modelling techniques.
- Developing a proposed PM tool incorporating learning and risk for CPs

Following the in-depth literature review in project performance management (focusing on but not limited to EVM), LC modelling and risks modelling; an exploration of performance assessment models is facilitated through a case study demonstration. Case study research method is considered suitable when the borders between phenomenon and background are not evidently obvious and wherein various bases of indication are required (Yin, 2013). Within the case study research, various learning effects on performance can be observed. Multiple case studies will be conducted to illustrate both the positive impacts of utilising and the negative impact of ignoring the contractor’s LC in performance assessment. The data analysis will be mainly conducted using the contractors archived data and observational study. Archival quantitative data have been defined as resources for contemporary research since they are recognised as an exceptional source of research material for secondary analysis (Corti and Thompson, 2004). In order to gather accurate information, it is necessary to observe the actual performance of construction projects and its learning rate (Yi and Chan, 2013) as well as KC over the course of the project’s front-end stages. Therefore, in the research design an observation is included to characterise the LC parameters in the contractor’s firm as well as risks facing the studied projects. The required data type includes the recorded data of contractor’s performance, e.g. planned and actual duration to extract LC coefficients, the status, trend, project schedule performance and related risks using case studies in construction industry. It is envisaged to use neural network to model these complex relations between variables. Artificial neural networks are forecasting methods that are based on simple mathematical models of human brain. They allow complex nonlinear relationships between the response variable and its predictors. In performance prediction process, the artificial neural network (ANN) forecasting method is envisaged to be employed to obtain more accurate and reliable performance forecasts (Zhang et al., 1998).

The combined performance and risk assessment model will aggregate data to design the best-fit learning curve for contractors. Thus, the traditional project performance tools, i.e. the EVM will be expanded to incorporate knowledge, risks and to include the learning that can dynamically influence the time and cost at completion.

5 Conclusion and Further Research

Measuring and increasing performance represents an important step in improving the CPs efficiency. PM monitors the project progress and actual performance compared to a baseline schedule. As construction projects are typically characterised by high level of risks as well as opportunities to capture relevant experiences, they must be continuously incorporated to improve the process. This paper established the real needs for better understanding and management of project particularly on earlier (pre-construction) stages in terms of performance improvement, lesson learned effects and highlights the various evaluation performance methods, as well as the potential for EVM to be used as a performance assessment technique. This paper also put forward a fresh perspective in looking into construction projects, particularly their front-end stages, from the knowledge creation (KC) perspective. Thus, various activities of the front-end stages of construction projects are argued to contain KC cycles in a spiralling knowledge creation manner. Future studies will further expand the EVM, incorporating risk assessment, project learning effectiveness and knowledge within the context of knowledge creation to develop a holistic and robust performance measurement tool with the view to enhance the performance level and continuous improvement in CPs.

6 References


**Contractor selection model for marine projects**

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**Abstract**

Hiring an appropriate contractor is a typical step towards achieving project success in marine projects. The appropriate contractor must have exceptional capability and techniques to deal with the risks and uncertainties that define the peculiarity of marine projects. In addition, the appropriate contractor must be able to drive project success in terms of budget, safety and work quality, amongst others. While these sound familiar in conventional projects, they are particularly unique in marine projects. Anecdotal evidence in normative literature suggests extant mechanisms for contractor selection are inappropriate for marine projects because most models for contractor selection are generic, and often do not have address the peculiarities of marine projects. For example, most of such models emphasise on financial and technical capacity, organisational management, and safety benchmarks in both eligibility processes and financial tendering. Whereas marine projects are sufficiently complex, requiring robust considerations beyond the superficial analysis of eligibility and selection criteria. Selection protocols must correlate with actual performance, whether experientially or normatively. We review literature on research attempts to achieve this in non-marine projects, and found limited correlation between contractor selection models and contractors’ actual performance. Findings also suggest procurement deliverables and the objectives of selection processes in traditional projects are not entirely the same as marine projects. From these, the paper points out how and why traditional selection models are inappropriate for marine projects. Implications of this will help unlock the relationship between procurement protocols and propensities for success or failure in marine and traditional projects.

**Keywords:** Contractor selection, marine projects, project success.

**1. Introduction**

Normative literature ascribes critical roles to contractors in project success. According to Zavadskas et al. (2008), inept contractors are unlikely to produce exceptional outcomes in construction projects. As a result, it is in the best interest of projects that stakeholders select appropriate contractors for their projects. Along the same line, it is equally important that stakeholders are able to support their contractors to succeed. This involves a whole lot of perspectives to their objective reality as they go through the various aspects of the crucial decisions they make. As a fundamental part of contractor selection processes, Topcu (2004) underlines the importance of evaluating contractors’ abilities to deliver potential projects in line with stakeholders’ expectations regarding quality, time and budget benchmarks before such contractors are allowed to bid. However, while
theories on selection models have remained unchanged for many years regardless of projects, these expectations are often not the same across projects and the subsectors within the construction industry. For example, causations of rework and overruns in building construction are not entirely the same as oil and gas projects as they are in building or civil construction projects (see Olaniran et al., 2017 and Flyvbjerg et al., 2004). According to these authors, similar factors in both sectors often behave differently when triggered by the same change events.

Selecting appropriate contractors based on projects’ unique attributes is a key factor towards the success of procurement processes. However, some clients often choose on the basis of lowest tender prices rather than an objective analysis of contractors’ abilities. According to Hatush and Skitmore (1998) and Russell and Skibniewski (1988), this practice is the prevailing cause of management difficulties during the life of a project. As a potential solution, Topcu (2004) suggests embracing a model that has the potential to integrate factors such as technical and financial capacity, performance history, commitment to quality management and unique characteristics of each project in selection process. These variables are used at the prequalification stage, in which contractors’ non-price attributes are analysed such that only considered candidate contractors are escalated to the price bidding phase. However, the process has been criticised in recent studies. Holt (2018) argues variables used for prequalification analysis often do not address the objectives of project performance; when trusted, they can mislead stakeholders.

Prequalification processes can apply differently in projects, depending on clients’ objectives and projects’ unique attributes. For example, in unique infrastructure projects, clients often benefit from selection models that are specific to the nature of their projects, in manners that ensure procurement processes add long term values to projects. This paper reviews the unique attributes of marine projects and illustrates a fit-for-purpose prequalification model that specifically addresses the uniqueness of procurement processes in such projects. First, a review of literature is presented on the unique attributes of marine projects, and later, the paper presents key features of selection criteria that help meet the unique objectives of marine projects.

2. Review of Literature

2.1 Attributes of Marine Projects

Marine environments are perilous. They can exacerbate inclement weather, and the terrains within which they exist are not least difficult. As a result, they require extreme complex designs, construction methods and technologies, most of which are not commonplace. In addition, support infrastructures required to drive marine are specialised and remote. Authors have written about this severely. For example, Anastasiou and Tsekos (1996) describes how weather events often trigger overruns in marine projects, and how such events are not often predictable. Cox and Cheyne (2000); Flin, Slaven, and Stewart (1996) and Haukelid (2008) have explained safety issues in marine environment. They all agree marine projects are many times more fatal than construction projects in any other sector. In addition to these, Tam and Shen (2012) identify resourcing as a significant issue in marine projects. The authors argue that technologies used in marine projects are intense, unique, complex and, are rare and expensive. They also identify the acute shortage of appropriate personnel to work on marine projects. In the view of Barinov (2007) also, marine projects often have significant impact on the economy. As a result, they often attract extensive political costs, both locally and internationally. According to Korbee, Mol, and Van Tatenhove (2014), marine projects require intense administrative and socio-political support. The implication of this is that their management costs can be huge, as though they could be social assets that may not yield extensive commercial benefits in the short run. Apparently, extant studies are quite clear on the uniqueness of marine projects and how their attributes often make them sensitive to chaotic events; in that events around their evolution are erratic and horrendous, and even when controlled, they trigger impacts that go beyond the remit of existing challenges.

Marine projects are not for all-comers. They require contractors that are highly competent, and are keen to succeed. Even where contractors are highly experienced, the margin for complacency is limited. Rather, successful contractors must be willing to learn and be capable of managing knowledge seamlessly, such that projects benefit where experiential knowledge in transferrable as well as where project situations are overly complex and unique (see Chimowsky et al., 2007, Love and Smith, 2016 and Yang et al., 2004).

2.2 Contractor Selection Criteria for Marine Projects

According to Palaneeswaran and Kumaraswamy (2001), the purpose of prequalification is to distinguish competent contractors from a pool of candidates. This is premised on the assumption that contractors that are considered to be incompetent during prequalification are likely fail or become vulnerable to performance challenges, whilst candidate contractors that are considered to be competent during prequalification are more likely to succeed and deliver projects to cost, schedule, safely and to the appropriate quality (Hatush and Skitmore 1997a; Huang et al. 2013; Movahedian Attar et al. 2013; The World Bank 2002). A startling finding in Hatush and Skitmore’s work is that there is no universal model on how prequalification criteria are applied. As a result, selection models can be used wrongly in some project environments and may be unable to help meet project objectives as planned. There could be many reasons for this. Prequalification criteria may be defined wrongly or may be set outside the premise of project objectives, and/or may be applied wrongly. For example, Olatunji (2008) articulates how clients still focus on lowest bid is the definite enabler of their decisions, irrespective of the differences in the considerable strengths of candidate contractors. Singh and Tiong (2006) report the same find about the Singaporean construction industry as well. Adoption of lowest bids, according to Fong and Choi (2000), dissipates the integrity of prequalification and does not always guarantee successful completion. This is not the only criticism that researchers have reported about prequalification – that is, prequalification makes no difference to contractor selection if clients only prioritise contract price over contractors’ actual quality; in that, it is logical to find two competent contractors of different capabilities.
seldom have the same price. Where exceptional capabilities of candidate contractors are identified during prequalification but are jettisoned during price bidding, apparently prequalification does not support contractors’ uniqueness and such contractors’ motivation for exceptional success has not been rewarded. In such instances, resourcing and managerial efficiency may have been ignored during assessment.

Many studies have pointed out prequalification criteria often used to select contractors in conventional construction projects (Aje, Oduasami and Ogunseimi 2009; Hatush and Skitmore 1997b; Holt, Olomolaiye and Harris 1994; Huang et al. 2013; Olatunji 2005). They identified criteria relating to contractors’ experience, recent performance, financial strength, technical strength, management and health and safety. These are good to know. However, how are they measured, and how do their measurements help achieve the goals of prequalification? For example, experience is measured by current capabilities and work strategy; current capability is measured by observed technical strength while work strategy is measured by perceived accuracy of method statement (Mahdi et al. 2002). Neither of these measures the high degree of complexity and uncertainty that characterise marine projects. This is because a contractor does not have to own all the technologies required to complete a complex project, and ownership does not entirely mean on-time availability and performance. Most contractors who have succeeded in major marine projects could have been disqualified on this basis alone. For appropriate and qualified contractor to be identified during prequalification, it is incumbent that assessors are most knowledgeable and skilled in related operations. An objective analysis of this is not often reported in construction management literature. It is possible that prequalification assessors do not have adequate cognate construction and business management experiences, and might be unable to articulate project objectives appropriately. Thus, they are likely to assess bidders wrongly. Redress following wrongful prequalification analysis is often not popular in construction management literature also.

In addition, different procurement methods are used in marine projects, and they are set to achieve different objectives. For example, in a Build Operate and Transfer (BOT) project, according to Tiong and Alum (1997), contractor’s package makes the most appeal to project owners if contractors are able to show they have an appropriate team of experts in their workforce, and have had the technical and financial capabilities, and the experience that helped them deliver in similar projects. Such candidates must also be strong on soft management skills such as communication, value engineering and negotiation skills. Whilst most of extant studies on prequalification in conventional projects iterate simplistic factors such as contractors’ financial strength, technical ability, management strategies, and safety record, an assessment in the context of marine projects require further precise evaluations of these characteristics based on project’s unique attributes. For example, how reliable is a contractor’s financial record that is based on account balance when there is no way of measuring the contractor’s liabilities such as unpaid wages, debts owed to suppliers, advance payments and unacquainted projects? How reliable is the information provided by a contractor on technical strength when quality of health and on-the-job availabilities of resources are unascertainable during prequalification? In addition, what amount of own work was in previous projects? How are clients able to measure the relationship between candidate contractors and their sub-contractors? What aspects of contractors’ safety culture are transferrable between projects, and what do these mean to the highly horrendous marine project environment? The knowledge gaps around these questions are important. If prequalification must drive project success, answers must be provided to them within the context of marine projects.

2.3 Domain-based Selection Criteria

Success is defined in marine projects not only by completion, rather it includes satisfying stakeholders (Olatunji 2018; Pinto and Slevin 1988). This is often measured wrongly in terms of pre-contract benchmarks. For example, Flyvberg, Skramis-Holm, and Buhl (2002); Flyvbjerg (2007); Flyvbjerg (2016) argue overruns deplete project success. Whilst Collins and Baccarini (2004) find such views prevalent amongst the respondents to their survey, they conclude the most important success factor is meeting clients’ needs. Love et al. (2015) argue overrun can facilitate meeting clients’ needs, and that most overrun causations are not triggered by contractors rather by project situations such as changes in clients’ requirements, political costs and other events outside the remits of projects. Thus, if the purpose of prequalification is to help identify competent contractors that can complete a project at the lowest cost and the shortest time, then marine project is the wrong place. The high level of uncertainty and complexity that characterise marine projects had meant overruns are often likely, and prequalification cannot prevent them. Instead of focusing on costs, Fong and Choi (2000) outline how clients should consider the uniqueness of projects in adding depth to conventional selection criteria for specialised projects such as marine projects. Marine projects involve multiple specialised disciplines, many of which are uncommon and vary from project to project. Prequalification should help clients to identify these and their availability to participate in the project. In addition, marine projects are cost-intensive. Extant measures of financial capability in conventional projects often mislead on this. For example, to demonstrate financial stability, contractors have often had to provide information regarding financial resources available to them, including audited accounts, bonding arrangement and financial statements. As pointed out earlier, measuring these could be misleading as none of the documents is able to help identify contractors’ liabilities accurately, either at the time of the assessment or during the execution of the proposed project. Rather, prequalification should be targeted at optimising financial performance of projects by ensuring that contractors’ liabilities are identified and do not interfere with project’s processes. Huang et al. (2013) has been outlined a methodology that helps on this.

Marine contractors must possess adequate equipment that are appropriate for shore and offshore operations. Sourcing, quality and availability of the equipment at the time of the operations can be assessed. Yeo and Ning (2006) have explained how these are major overruns triggers in major projects. A way to assess them is to observe contractors’ operation and analyse the relationship they may have with equipment vendors and suppliers.

In addition, contractors are seldom assessed on their commitments to research and organizational development. However, most complex projects including in marine environment, require intense bifurcation (Akamnu et al. 2016; Olatunji 2018). During
prequalification, candidate contractors can be assessed by considering their digital technologies, research culture, organizational policies on innovation and development, and proposed work methods.

Tam (2012) argues marine projects are severely risky. This can be ameliorated. Clients can assess contractors’ safety culture and records. They can also examine causation probabilities around elements of marine environment, including by applying risk management mechanisms. Tang and Bittner (2014) identified uncertainty and dynamic nature of pre-bid and post-bid situations underlying complex construction projects. They argue an efficient way to achieve success in complex projects is to adopt systematic approaches that adds value to projects and satisfies stakeholder’s expectations.

3. Contractor Selection Methodologies

According to Doloi (2009), clients often have difficulties in identifying and predicting the contractors’ capabilities correctly through prequalification processes. Conventional practices relating to this can be classified in two, namely: filtering and ranking procedures. In Filtering procedures, contractors are shortlisted only when they satisfy all criteria nominated by project authority. Non-compliance to a single criterion to trigger disqualification (Palaneeswaran and Kumaraswamy 2001). In ranking procedure however, overall achievement is via a scoring system. Scores are awarded to contractors based on different parameters, defined by project objectives. Contractors can be escalated to next stage if a certain cut-off score is achieved, even if found wanting in certain criteria. Figures 1 and 2 illustrate the models.

In both methods, competency of the evaluation authority is crucial. Variables can be compensatory in a ranking procedure. This can lead to dire outcomes as criteria which were considered non-critical at the time of the assessment could turn out to be critical during project execution. Assessors need to understand this perfectly. In addition, filtering procedure requires an understanding of the objective correlation between selection criteria. They must be able to interpret them correctly also. Since marine projects are intensely sensitive to cost, safety, resourcing and quality, a mixed method approach is appropriate. Contractors can be filtered and ranked diligently. The work of Cagno et al. (2001), El-Rayes (2001) and Alsugair (1999) regarding a mixed-method approach to contractor selection is instructive. They categorised selection criteria into eight themes. Their methodology explains the relationships between the selection criteria. The themes include experience, financial stability, previous performance, work quality, current workload, available resources, organisational structure, and technological capability. These factors apply to marine projects. However, they require further development. Assessors are able to set up delimiters and use scoring systems as may apply to project objectives. The missing link however, is the correlation between the assessment and contractors’ actual attributes. A way to go is to consider the integration of quantitative and qualitative methods of evaluation, and ensure that assessors are knowledgeable about how candidate contractors operate. It is also important to ensure evaluations do not deviate from project objectives.

4 Implications

Construction projects are different in nature. Thus they different strategies to help achieve their goals right from very early stages and throughout procurement processes. In projects with peculiar characteristics, contractor selection model needs to be precise. They need to be objective beyond superficial attributes of conventional models. Prequalification processes should reward contractors’ previous achievement and values. New proposed model is an integration of previous models with the potential to decline the impact of inappropriate contractor by employing extra filtration/modifications in the process. Considering the intense investments in marine projects, schedule overrun caused by inappropriate contractor will result in a disaster. Furthermore, replacing the improper contractor will definitely imposes time and cost overrun to the ongoing project. Potential proposed model comprises of identifying the common and unique affecting factors based on the unique attributes of each project, assessing based on checkpoint/scoring legislations by the authorised committee and selecting the most appropriate contractor based on the outcome score. Figure 3 illustrates the proposed model.

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they target. For prequalification processes to be successful in contractor selection for marine projects, selection criteria must consider elements that relate to actual performance of candidate contractors. Evidence that correlate with performance can be evaluated qualitatively and quantitatively by appropriate assessors. Competence of the evaluation authority is very crucial. Based on review of previous studies on the study, a conceptual model was proposed with the potential to facilitate the development of improved prequalification mechanism for marine projects. With regards to contractor’s actual performance, the presented model is seeking to eliminate incapable contractors, enhance the selection process based on scope of the project, minimize the likelihood of overruns caused by contractors’ incompetence and ameliorate the stakeholders’ satisfaction by highlighting the value-for-money concept instead of lowest bid price. The model has not been developed from empirical data. Further studies is required for this. In addition, the next stage of the study is to advance towards determination of eligibility checkpoints in different types of marine projects with regards to their unique attributes and scope of work.

6 References


5 Conclusion and Further Research

As described before, distinctive characteristics in a construction project can be employed as an instrument to append additional measures to the selection process. The proposed model indicates the capability of the appropriate contractor in successful delivery of the project. Some critical checkpoints applicable in marine projects as additional agents to the selection process include actual performance in similar projects, experience in similar region, proficient technical staff in different disciplines, proven financial capability, adequate marine equipment, size/number of the recent completed projects and systematic problem solving mechanism.

Figure 3. Potential contractor selection model for marine projects


Analysing building compliance reports: A New Zealand study

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Abstract:
Building Industry turnover has increased since 2004 with a slight decrease during the 2008 recession. The current spike in new builds mean there is potential for problems to arise from the construction process. Although procedural arrangements within the building consenting systems serve to ensure that new builds are delivered to the right standards, there are challenges with achieving full compliance. There is evidence that suggests a significant failure percentage of building inspections during construction. Therefore, the aim of this study is to analyse failure patterns within different stages of residential building inspection. Data on residential buildings was obtained from Building Council inspection records for an urban council in New Zealand. The inspection records cover January 2013 till June 2016, a four-year overview of a trend in passed and failed inspections. These inspection results provide information on areas of residential building construction that require constructors’ performance improvement. This way both Council and Clients can work collaboratively to achieve common compliance goals. Furthermore the findings contribute towards reducing reworks and remediation which cause building cost escalations and an overall poor performance reputation.

Keywords:
Building, compliance, failings, residential, inspection

1 Introduction
There is an increase in residential building construction works as the population of the major cities in New Zealand rise. Therefore it is becoming important to focus on the issue of non-compliance with building regulation during the construction of homes in New Zealand. Non-compliance are a cost to every party in the construction industry. To the project owner, it means less value realised from their investment; to constructors, it is reworks and remediation which cause building cost escalations and an overall reputation of poor performance. The current study focuses on Auckland which is the biggest city in New Zealand with a population of 1.4 Million according to the 2013 census by Statistics New Zealand. Within the years 1991 to 2013, Auckland experienced an increase of about 430,000 people (Statistics New Zealand, 2013). Further the fastest population and household growth over 20 years, is projected in the outer local board areas (Statistics New Zealand, 2013). This growth in addition to increasing ageing population, contribute to high demands which is reflected in current housing market shortages.

According to Lin (2015) Auckland needs to build 13,000 new homes a year to keep up with housing demand. However figures released by Housing New Zealand indicate only 2000 houses per year are being built. This indicate a deficit of 11,000 when compared to the 13,000 projected (Lin, 2015). Although the value of building consents being issued is on the increase (about 18.9%) year in year out.

The increase in residential build requires a focus on building performance, as anecdotal evidence suggest that about 25 to 40% of all building inspections generally fail due to poor performance and related reasons. The current study provides insight to the pattern of non-compliance at different stages of the building inspection process. This information is useful to builders, residential building owners and regulatory authorities. Such key information helps the understanding of the dynamics behind the construction of new dwellings in New Zealand.

2 Literature Review
The following sub sections provide a brief review of issues relevant to building compliance in New Zealand. The regulatory environment for consent processing is first reviewed, followed by residential building quality achievement. The section further explains the different type of inspections conducted for residential buildings within the study area. Finally, the categories of residential buildings in terms of their complexities and groupings is briefly described, to give context to the discussion of research findings in later sections.

2.1 The Building Act and Councils’ role
Central to quality and performance improvement of new constructions are regulations and standards (Baiche, Walliman, & Ogden, 2006). In New Zealand, the Building Act describes the various roles that must be undertaken by both Territorial Authorities and Building Consent Authorities (BCAs) towards building construction. Territorial Authorities have oversight functions but the responsibility for compliance to building regulations lie with the BCAs. BCAs ensure that all prescribed requirements for construction activities conform to the Building Regulations 2004, and that certifications are completed in full by building practitioners for all works executed. The building consent process ultimately ends with the issuance of a code compliance certificate (CCC), which means that all the Building Code and Building Regulations have been met and the building is suitable and safe for occupancy (Auckland Council, 2016).

Building construction control aims to provide quality buildings that are fit for purpose, provide safe spaces for people to occupy, are durable and provide the sense of well-being and amenity expected in any international city (Building Act, 2004). Building quality is best achieved during construction, when the council provides independent surety of that quality, through inspections to ensure Building Code compliance (Auckland Council, 2016). Auckland Council believes that if inspections are not undertaking diligently, robustly and fairly, an opportunity to influence the delivery of quality buildings will be missed.

2.2 Residential buildings and quality achievement
Problems with quality and performance achievement of buildings within the construction industry in the last decade remain unresolved (Forcada, Macarulla, Gangolesl, & Casals, 2014; Baiche, Walliman, & Ogden, 2006; Lundkvist, Meiling, & Sandberg, 2014; Mahamid, 2014; Bikçe & Çelik, 2016; Mills, Love, & Williams, 2009; Abdul-Rahman, Wang, Lincoln, & Khoo, 2014). An assessment of construction defects by Forcada, Macarulla, Gangolesl and Casals (2014) for 68 residential buildings in Spain,
demonstrated that most common construction defects are caused by inappropriate installation of structural elements, surface appearance due to poor workmanship and formwork preparation, which later affected intended functionality. The study showed that installation of structural elements were carelessly overlooked and inspected which later compromised the integrity of the building strength. Furthermore, incorrect positioning of the frames in relation to the foundation caused capillary action that deteriorated the structural framings faster than its intended durability. There were indications of honeycombed, concrete surface due to poor workmanship and use of inappropriate tools.

Mills, Love and Williams (2009) estimated rework costs in buildings to be about 5% of contract values. They reported that the extent of illegal building work in Australia is minimal but such buildings are ordered to be demolished or excluded from HGF insurance scheme. The major source of defects in Australian buildings is from water ingress and poor footings (Mills, Love, & Williams, 2009). Other areas of defects are from water hammer and leaking windows sill gaps, cracking, and dampness.

A study by Lundkvist, Meiling and Sandberg (2014) in Sweden, show that inspections are more regulatory focused and lack important contextual information. Lundkvist, Meiling and Sandberg (2014) suggests that an enhanced inspection platform could better manage and standardise construction quality improvement in Sweden. Using a continuous improvement methodology a framework for defect management can be used to keep track and reduce defects. Mahamid (2014) in the same light proposed proper planning, design and information documentation to reduce poor quality of completed works.

Whilst it is important to reduce defects at handover of new residential buildings, Rotimi, Tokey, and Rotimi (2015) conclude that performance could be greatly enhanced through a high quality of building inspection systems. Beacon (2010) confirms the role of councils in assisting with Building Code achievement. Building consent authorities through a streamlined consent and inspection process that are based on sound information and consistent practices, can contribute positively to building performance (Beacon, 2010). However there is insufficient information on the results of building inspections, particularly on failings of building inspections (Rotimi, 2013). This is the relevance of the current study investigation that seeks to examine failed and passed inspection data, with a view to improving overall building production.

2.3 Type of Inspections

Having understood the importance of inspections in buildings, this section gives an outline of the types of inspection recommended by Auckland Council in New Zealand. There are a range of inspections undertaken during the course of construction which are project specific and are identified during the building consent application process. Table 1 provides a summary of 12 different stages of inspection that may be required for residential buildings that fall within the certain ranges of National BCA competency assessment system levels. It is possible to have more or less than these 12 types of inspection. This type of inspections were selected in this study because they are typical for most residential buildings. The table identifies the stages and provides a brief description of the inspection.

### Table 1. Typical residential building inspection stages

<table>
<thead>
<tr>
<th>Type of inspections</th>
<th>Description of inspection</th>
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<tbody>
<tr>
<td>Foundation</td>
<td>An inspection of strip or bored pile foundations before the concrete is poured.</td>
</tr>
<tr>
<td>Concrete block</td>
<td>An inspection of block work construction, cast in situ panels, columns or walls before the concrete is poured.</td>
</tr>
<tr>
<td>Concrete floor slab</td>
<td>An inspection carried out before the concrete is poured, it excludes plumbing, of any floor slab and its associated building work.</td>
</tr>
<tr>
<td>Framing</td>
<td>A detailed inspection of the timber structure of the building before the roof cladding and building wraps are installed.</td>
</tr>
<tr>
<td>Cavity wrap</td>
<td>An inspection of the building wrap and cavity construction before the cladding is installed.</td>
</tr>
<tr>
<td>Preenline Plumbing</td>
<td>An inspection of any plumbing works within the building prior to be lined.</td>
</tr>
<tr>
<td>Preenline Build</td>
<td>An inspection of the building work before the installation of any internal linings.</td>
</tr>
<tr>
<td>Cladding</td>
<td>An inspection of the specific cladding installation approved in the building consent.</td>
</tr>
<tr>
<td>Tanking/Water-proofing</td>
<td>An inspection of a roof, deck or internal wet area membrane. Deck and roof membrane also covered in wet area inspection.</td>
</tr>
<tr>
<td>Postline</td>
<td>An inspection of the building linings required to provide the building work with structural bracing or wet wall lining. Also includes inspections of any fire-rated product installed to comply with the building consent and the building code.</td>
</tr>
<tr>
<td>Drainage</td>
<td>An inspection of any surface water or foul water drainage system associated with the building consent.</td>
</tr>
<tr>
<td>Residential Final</td>
<td>A final inspection to confirm the building work covered by the approved building consent has been completed and complies with that consent and the building code.</td>
</tr>
</tbody>
</table>

### Table 2. Summary of residential building types in New Zealand

<table>
<thead>
<tr>
<th>Residential type</th>
<th>Risk matrix</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential type 1</td>
<td>less than or equal to 6</td>
<td>residential outbuildings and ancillary buildings defined by the Building Regulations 1992 (e.g single storey)</td>
</tr>
<tr>
<td>Residential type 2</td>
<td>less than or equal to 12</td>
<td>more complicated and poses more risk (e.g a two storey family home with lower roof attachments and decks on the first floor)</td>
</tr>
<tr>
<td>Residential type 3</td>
<td>13–20</td>
<td>Detached dwellings (SD) or other dwellings (SR) that are less than or equal to three storeys’ but limited to vertical plane re separation and direct egress to the outside (e.g apartments and terrace buildings)</td>
</tr>
</tbody>
</table>
2.4 Type of buildings

The complexities and grouping of residential buildings in New Zealand, is based on a national competency system’s framework, starting with the legislative requirements through to the tools of assessment. Under this competency assessment system tool, residential buildings were divided into three types, namely: Residential 1, Residential 2 and Residential 3 (R1, R2, and R3 respectively). Table 2 provides a summary of the competency assessment for residential buildings.

3 Research Methodology

The aim of the research is to investigate common failings at the inspection of buildings by Building Consent Authorities. The study employs a quantitative method to allow the extraction and manipulation of pre-existing data using computational techniques and display methods. This is in line with Craig, (2008), who suggests that quantitative researchers tend to use a multitude of quantitative terms such as frequencies, numbers, amounts, trends, patterns and relationships for data analysis. The data were extracted from the Auckland Council records. The focus was based on residential buildings with complexities ranging from R1 to R3, as was previously defined in Table 2. The study area selected comprise two regional areas out of five within the larger Auckland regional council. Data from these two areas have been combined for the purposes of the current study investigation. The two regional areas were selected because they contained the highest number of number of building construction per area in comparison to other cities in New Zealand.

The inspection records extracted for the study covered January 2013 to June 2016 period. Thus a four-year overview of a trend that may form in terms of pass and failed inspections. The raw data added up to about 146,000 of inspection records undertaken within the period. Statistics obtained comprise of all fields such as consent number, date and type of inspection undertaken, result of the inspection, complexities of the build, the inspector who undertook the inspection and the comments from the inspector on reasons behind the outcome of inspection whether passed or failed.

4 Findings and Discussion

In this section presents a description of the results of the data obtained from the Council records as explained previously. From the 146,000 raw data spreadsheet extracted, pivot tables were constructed within MS Excel to filter the relevant fields needed for the current study. The data shows number of inspections by complexity, passed and failed inspection numbers and number of inspection types within the study period.

4.1 Inspections by building complexity

A summary of all inspection records for the study period is presented in Table 3. The information is presented in line with complexities of the buildings inspected (i.e. R1, R2 and R3). The data set shows a general increase in total number of inspections from the base year to the half year record in 2016.

4.2 Passed and failed inspections

In this section, a summary of passed and failed inspections is presented in Table 4. This was obtained by filtering the data set over the study period. As is observed from Table 4, there were about 19% (28,368) total failed inspections between 2013 and 2016. Compared to about 81% (118,163) total passed inspections. Table 4 is re-presented in a chart form to display diagrammatical differences between the passed and failed inspections (see Figure 1).
4.3 Passed and failed inspections by inspection types

To meet the objectives of the current study, a further filtering of the Council records was undertaken to determine the passed and failed inspections numbers in line with the type of inspections that was undertaken by the Council inspectors. 12 major inspection types were identified and described in the literature section. The data obtained is summarised in Table 5.

For the purpose of this study, the data in Table 5 has been ranked in ascending order from the inspection type with the least number of failures to the type with the highest number of failures. Thus, Preline Plumbing has the least number (399) of failed inspections compared to Residential Final which recorded the most failed number (6946) of inspections within the study period.

The outcome of this summary in Table 5 provides clear indications of the top four most commonly failed inspections. These were identified as Residential final, Preline building, Framing and Foundation Inspection. Values in percentages have been presented alongside the numbers for ease of comparison and for clarity of expression. Residential final inspection is the last inspection within the building consent process, carried out by council inspectors before the issuance of code compliance certificates CCC. Failure in this aspect of inspection means a delay in the issuance of CCC.

Preline building inspections are necessary to ensure that buildings are weathertight and all joinery and exterior flashings have been installed properly. About 13% of inspections at the preline stage fail. Further, 12% of framing inspection fails during building construction. This is regarded as one of the more complicated inspections as one goes up the building complexity scale from R1 to R3. Foundation inspections are important and would normally deserve extra scrutiny by council inspectors. Foundation inspections constitute several sub inspections depending on the foundation design of the buildings.

From the foregoing, the extent of failed inspections in residential buildings have been ascertained. The four most failed inspection types were identified as Residential Final, Preline Build, Framing and Foundation inspections. These are key stages in residential construction that require more attention by both the constructor and the inspectors. Basically, before any aspect of construction work is covered, they must comply to avoid expensive maintenance in the future. Fail rate at the ‘residential final’ would relate more to poor attention to details and workmanship.

Final inspection check sheets are very detailed and time consuming. The check sheets require full checks of the areas covered under the building consent process and any variations during building construction. Final checks include checks for the interior and exterior aspects of residential buildings. These checks coincide with the time when final finishing touches are being made to buildings thus should be expected that more scrutiny will realise more failures.

Preline inspections follow cavity wrap and cladding inspection. The inspection is to ensure that buildings are weathertight and all joinery and exterior flashings have been installed properly. At this stage the roof cladding and all roof junctions and are weatherproofed and installed as per manufacturers specifications. Council inspectors conducting a thorough investigation starting from the internal braces to ensure all bracing elements have been achieved, and all fixings are installed. Windows and doors are to be pressure sealed and expanding foam applied after the Pef rod in any window and door openings. Inspections also ensure all insulations are in place and that the correct value and type of insulation is installed. Checks on plumbing systems is part of the preline inspection. All water supply pipes are pressure tested and other water test carried to ensure that wastes are not leaking.

Framing inspections follow foundation and slab inspections. There are few different areas of the building construction that falls under framing inspection. Decks, balustrade to membrane roof and decks fall under framing inspections.

Finally, foundation is one of the top four identified in the current study as failing inspection. Foundation inspections are important and would normally deserve extra scrutiny by council inspectors. Foundation inspections constitute several sub inspections depending on the foundation design of the buildings.

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5 Conclusion and Further Research

The objectives of this current study was to identify common failings in inspection during the construction of residential buildings in New Zealand. The study was desired to provide some indicators of performance quality by residential building contractors and to identify areas of future improvement. The research involved extraction of data from the records of building inspection reports held by the Auckland Regional Council in New Zealand. Data on two regional areas were used for the current analysis, which had about 146,000 inspections records for the period of 2013 to mid-2016.

Four key areas of building inspections stages had a high failure rate which deserves attention by all residential building practitioners. These are the final building inspection stage, Preline build, Framing and Foundation inspection stages in that order. These may suggest a lack of understanding of building code requirement or poor attention to details. There may also be skill level issues that may need to be addressed considering the large numbers increase, the need for more thorough inspections becomes necessary. Councils and Clients would need to work more collaboratively to achieve common compliance goals. This will contribute towards reducing reworks and remediation which cause building cost escalation and an overall poor performance reputation.

The current study is limited in the generalisations that can be made of the study findings. Further research is needed to cover a wider study period, collation of information from more regional areas and councils within New Zealand so that the result could be representative of the whole country. Furthermore, it would be worthwhile determining the reasons for failure of these inspections to serve as a preventative approach to non-achievement of expected residential building qualities.

6 Acknowledgement

The authors wish to acknowledge the Auckland Council, New Zealand for providing access to the data used for the research project.

7 References


Collaborative international industry-university research training in infrastructure projects: an Australian-Indonesian case study

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Abstract:
Infrastructure project management research often requires the use of qualitative research methodology to reflect the richness of data and the complexity of such. When undertaken across international borders this often challenges research teams due to work restrictions and amount of time that can be spent on data gathering. This paper reflects on the successful use of the case study method of organised research work undertaken by graduate students and researchers in Indonesia and Australia through industry engagement. The case study involved six universities in Indonesia and Australia and government and private sector seaport industry players. The paper examines the use of qualitative research methods to explore themes of sustainability, technology and innovation in attracting financing for infrastructure development projects. From the viewpoint of the universities and researchers, the project provided a real-life situation where researchers work closely with industry to investigate and analyse problems. For industry, it provided an opportunity for competitors and customers to work together to examine issues related to sustainability, technology and innovation and to initiate solutions for these issues.

Keywords:
Research training, University-Industry collaboration, Infrastructure project management

1 Introduction

Large infrastructure projects such as port development projects involve a range of construction activities such as wharfs, jetties, terminal buildings, cranes, roads and even shuttle railways. These are now increasingly being undertaken by large global organisations. The infrastructure project management research that investigates these projects typically requires researchers to work collaboratively with colleagues from different institutions. While it is recognised that universities will train their researchers in cognitive and technical skills required for independent research, there is evidence to show that cognitive and intellectual skills at an individual level are not sufficient for such projects as the research is done by teams instead of by individuals (Wuchty et al., 2007). Teaching and learning research methods that are too highly focused on individual learning may not be developing the right competencies for researchers to work at an international level.

Working in collaborative research requires researchers to be part of teams. To be highly effective teams, team members need more than just technical skills and cognitive skills at an individual level and would need high levels of interpersonal and communication skills. Parker and Hackett (2012) found that social bonds developed between research teams are also very important in high-performance collaborations as researchers spend a lot of time together in collecting and analysing data. These interpersonal skills and the ability to work with other researchers are therefore very important skills that must be developed.

Developing the correct research competencies in graduate students is also important. In this paper, we explore a case study of successful collaborative research between institutions in Indonesia and Australia involving a large infrastructure management research project. The paper discusses the research activities, the theoretical basis for the action-research as well as showcases the reflections and feedback from the research students and the research supervisors.

2 Literature Review

The theoretical basis for experiential learning in the collaborative research process

Kolb (1984) provided a theoretical base for action-research, where learning is experiential and all knowledge is “created through the transformation of experience”. Learners go through a four-stage model of concrete experience, reflective observation, abstract conceptualisation and action experimentation. This learning model can be best described as a spiral of cycles. In a research context, experiential learning emphasises the importance of activities such as fieldwork and interviews, which the learner experiences and then reflects on during the analysis stage (Chuaprapaisilp, 1997). The type of experience, the role of reflection and the application of theory are critical in the experiential learning cycle. Student engagement can be enhanced by learning based on real or simulated industry experience (Mehriens, 2011).

2.1 Reflective learning

Taking time to reflect on activities and concepts are important parts of experiential learning. Reflective learning journals, when implemented within an educational program, have been reported to be useful in enhancing learning in a construction program (Baccarini, 2004). In a similar way, research activities should be reflected and documented at some point in the process.

2.2 Sharing interdisciplinary skills

Effective interdisciplinary collaboration requires careful articulation of the project goals and processes as research has found that there could be fundamental differences in what these mean for team members (Benda et al., 2002; Eigenbrode et al., 2007). Individual team members having different background and training are likely to have different viewpoints and philosophies (Eigenbrode et al., 2007). Such differences may show up in distinctive ways such as the researchers’ motivation for research, their preferred methodology, their individual values, objectivity, and the amount and kind of evidence that they require for knowledge generation. The challenges of cross-disciplinary research are often overlooked and may even arise within disciplines where broad assumptions have been made (e.g., between theoreticians and empiricists, or between modelers and experimentalists. (Eigenbrode et al., 2007). The differences are fundamental to the way researchers operate so they are directly linked to the collaboration’s success. Without
clear sharing, communication, and appreciation of such differences, teams struggle to find common ground and this will limit the research productivity.

2.3 Good interpersonal skills

Another aspect of collaborative research teams is that members are required to communicate effectively. This means having good interpersonal skills which encompasses social sensitivity and emotional engagement (Wooley et al., 2010). This positively influences interactions among team members that then positively influence research outcomes. The importance of these fundamental skills in a range of different contexts is well supported by research. For instance, Wooley et al. (2010) reported that measures of social sensitivity were the main predictor of group intelligence (i.e. ability to solve problems as a group), and were stronger predictors than the individual cognitive intelligence of group members. These abilities were found to influence team project performance and productivity in a real-world business environment (Pentland, 2012).

Social engagement also influenced the success of business leaders and the groups they supervised (Zenger and Folkman, 2009). The importance of such abilities is also supported by the work of Goldstein (2009) who found that emotional intelligence was the most important factor to predict "presidential success", more so than political skill, vision, cognitive style, or ability to communicate. Regardless of discipline or question of interest, group problem-solving requires effective communication and collaboration at the team level in addition to the individual level (Chevrilil, et al., 2009). Such skills would be extremely useful when collaborating on large projects at an international level.

3 Research Methodology

3.1 The research project

The research project discussed in this paper was funded by the Australia-Indonesian Centre as a strategic research project titled “Efficient Facilitation of Infrastructure Projects” (Australia-Indonesia Centre, 2017). The focus was on port development projects in Indonesia and Australia with the aim to find financing options that best attract investment support in both Indonesia and Australia. A range of financing options and their mechanisms were initially considered and then narrowed down to a set of options that include: (1) the use of special economic zones; (2) integrated industry port-industry estates; (3) intercountry loans; (4) Public-private partnerships; (5) Government-led projects; and (6) lease or asset recycling. In investigating these finance options, a range of parameters such as ownership, operational efficiency, governmental processes, business and regulatory context in both counties, and risk were considered. Beginning in mid-2016, the project spanned more than two years. The lead investigators are from three prestigious universities, The University of Melbourne (UoM), Universitas Indonesia (UI) and Universitas Gadjah Mada (UGM). Academics from other Universities including The University of New South Wales and the Institute Technologi Sepember (ITS), also played a supporting role. This project draws from the research activities of two PhD projects, one masters by research student, four master final year projects (total five students). Nine research assistants from Australia (Indonesian students, mostly postgraduate masters level) and four Indonesian research assistants, supported the activity over the course of the project. The teams were also cross-disciplinary in nature with expertise associated with infrastructure engineering and project management (UoM and UNSW), strategic management and finance (UI), transport engineering (UGM and ITS) and transport economics (Monash).

To understand what is important in the process, the project involved a range of stakeholders in both Australia (Melbourne) and Indonesia (Jakarta and Surabaya). These stakeholders work in a range of organisations from government departments, governmental agencies, state owned enterprises, port authorities, terminal operators, supply chain service providers, shipping lines, consultants to constructors.

3.2 Research process

The study utilised a number of different methodologies to investigate the perceptions of the various stakeholders associated with ports. It utilised: forums, on-line surveys, Focus Group Discussions (FGD), in-depth interviews, and workshops. In addition, key port related government personnel, industries and organisations were approached by the researchers to take part in the FGDs or to complete the online survey. Ethics approval for the research was obtained from the Human Research Ethics Committee of The University of Melbourne in August 2017. The research partners from Indonesia obtained the necessary approval required from their respective universities.

3.2.1 Research forum

A research forum was held in Melbourne, Australia in July 2017 to exchange ideas and discuss how best to explore the research topic and progress the study. The profile of the forum participants is detailed in Table 1 and included a balance of researchers, advisors and students.

<table>
<thead>
<tr>
<th>Category</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researcher/Government Advisors</td>
<td>Study chief investigator, Academic (Project management), UoM</td>
</tr>
<tr>
<td></td>
<td>Co-lead researcher, Professor in Strategy, Universitas Gadjah Mada (UGM), Indonesia</td>
</tr>
<tr>
<td>University Research staff</td>
<td>Two academics/researchers in Project Management, UoM</td>
</tr>
<tr>
<td></td>
<td>Two academics in finance, international business and supply chain (UI)</td>
</tr>
<tr>
<td></td>
<td>Research Fellow, UoM</td>
</tr>
<tr>
<td></td>
<td>Transport Professor, Universitas Gadjah Mada (UGM)</td>
</tr>
<tr>
<td></td>
<td>Professor of Law with expertise is public-private partnerships, privatisation and regulation (Monash)</td>
</tr>
<tr>
<td></td>
<td>A PhD student, UoM</td>
</tr>
<tr>
<td></td>
<td>4 Masters students, UoM</td>
</tr>
<tr>
<td>Private Sector Advisors</td>
<td>As Emeritus Professor of transport (UNSW)</td>
</tr>
<tr>
<td></td>
<td>Commercial PPP infrastructure advisor</td>
</tr>
<tr>
<td></td>
<td>Finance lawyer</td>
</tr>
<tr>
<td></td>
<td>A geographer and transport logistics expert</td>
</tr>
<tr>
<td></td>
<td>Port project sponsors and financiers both domestically and internationally</td>
</tr>
</tbody>
</table>

The forum provided an opportunity to exchange ideas and clarify thoughts, to update all the attendees on the work that had been done so far, to discuss the content of the online surveys that were being developed, to discuss the research monograph on Infrastructure Investment in Indonesia: a focus on ports that was being written as part of the study, and to refine the key questions that needed to be asked during the study. The discussion identified the work being done by the World Bank and the World Economic Forum.
related to ease of and barriers to doing business in countries around the world and highlighted recent reforms made by the Indonesian Government to reduce high logistics/ freight costs in Indonesia. Aspects of this were subsequently incorporated in the online surveys.

### 3.2.2 On-line surveys

The online surveys were designed to investigate various themes related to “Efficient Facilitation of Major Infrastructure Projects—port planning and development”, namely: investment decisions, port/city performance, barriers to doing business, funding and financing, port sustainability, procurement and capacity building. The questionnaires were reviewed between the Australian (UoM) and Indonesian University partners (UI and UGM) via email and then via video conferences.

An Australian and Indonesian version of the survey was prepared. The surveys contained both quantitative and qualitative questions. Most questions were the same between both questionnaires except for a few related to specific funding models only available in Australia or Indonesia and demographic information being sought where descriptions of Government agencies were slightly different between the two countries. The Indonesian version of the survey was translated into Indonesian by an Indonesian post graduate Engineering student at the UoM who was engaged as a research assistant (RA) on the study. Questions were offered in both Indonesian and English on the Indonesian on-line survey. The surveys were hosted by SurveyMonkey™. The online Indonesian survey was launched in September 2017 and the Australian version of the survey in November 2017. Both surveys were closed in May 2018. At the completion of the survey, the responses to qualitative questions from the Indonesian survey were translated into English by our Indonesian RA in Australia whereas the Indonesian partners were provided with the excel databases directly downloaded from Survey Monkey.

### 3.2.3 Focus Group Discussions

The Focus Group Discussions that were held in Jakarta, Indonesia in September 2017 and in Australia in February 2018 were organised by the University research partners in each country. In Indonesia, post graduate and undergraduate students were engaged to assist the lead researchers from that country to organise the FGD and to contact port, government and industry stakeholders to invite them to take part in the FGD. Respondents to the online surveys who indicated a willingness to take part in the FGD in each country included a Master of Engineering Project Management student from UGM who were responsible for transcribing the recordings for their respective institution. Separate to this, some independent in-depth interviews have been conducted by the PhD student from the UoM in Australia with individuals who have a significant involvement with ports in Australia. The questions asked of attendees at the FGDs and in-depth interviews are consistent and relate to port development and funding and financing.

### 3.2.4 In-depth interviews

In-depth interviews of senior port executives were conducted in Surabaya, Indonesia in April 2018. These interviews followed a seminar related to port research and were entirely managed by a PhD student and academic from UGM and two post graduate Indonesian Engineering Project Management Students from UoM, Australia. Each team was responsible for transcribing the recordings for their respective institution. Separate to this, some independent in-depth interviews have been conducted by the PhD student from the UoM in Australia with individuals who have a significant involvement with ports in Australia. The questions asked of attendees at the FGDs and in-depth interviews are consistent and relate to port development and funding and financing.

### 3.2.5 Industry engagement

Industry engagement by the research team occurred at various points: via invitations to take part in the online survey, the FGDs, in-depth interviews, and by direct contact with ports, port related organisations and industries and relevant government bodies. To further optimise engagement with the online port survey in Australia, the research fellow from the UoM contacted the Chief Executive Officer of the professional body representing ports around Australia and senior members of peak professional logistics and transport organisations to advise them about the online port survey and to ask whether they would advertise the survey to their membership. Many of these port and industry contacts were subsequently invited to take part in a networking dinner with Indonesian delegates and University partners who travelled to Australia for the Port Competitiveness and Financing Workshop held in April 2018 which showcased port research to-date from all the University partners in Australia and Indonesia and offered training to visiting Indonesian delegates. At the workshop and networking dinner, eight of the Indonesian Masters students (from UoM) who were assisting with the study as RAs were engaged to assist with and take part in the workshop and the networking dinner. The Consul General of Indonesia was also an invited guest at the networking dinner.

### 3.2.6 Workshop and dissemination of information

The workshop provided a forum in which to disseminate research findings and information related to the study to key port industry stakeholders and players. The workshop also provided an opportunity for port stakeholders to raise specific issues they face at their ports and to discuss these with presenters, researchers and attendees. These sessions also promoted further engagement with industry.

### 4 Findings and Discussion

#### 4.1 Experiences of the research

The collaborative research approach undertaken by the researchers from the UoM, UI and UGM has resulted in strengthened relationships with the university partners in Indonesia and Australia. It has built goodwill between the research participants. The visits to Indonesia by the Melbourne research team and the visits to Australia by the Indonesian research teams have increased engagement between the groups and fostered a willingness to collaborate and share information.

The online Australian survey and approaches to senior port executives, government, industry representatives and peak bodies around Australia to take part in the survey and the invitations to the networking dinner in Melbourne in April 2018 opened the research partners to a broader industry forum. The profile of the AIC, the research teams and the work being undertaken has been raised both in Indonesia and Australia as a consequence of this. A greater understanding of the culture within each of the countries has also been
developed. Postgraduate students who have been involved in the study as research assistants have also commented on how the opportunity to take part in the research has enhanced their educational experience at the University.

4.1.1 What the students say
Involving postgraduate students as RAs in this collaborative port research study has allowed them to learn, develop and apply their skills to an existing international study. The exposure to the research team has enabled them to see how projects are managed and developed and how they can contribute to the overall success of a study. They have also been able to learn from their supervisors. They have learnt by actually ‘doing’.

An additional benefit of being involved in this study is that the students have also had the opportunity to meet senior Indonesian and Australian port executives, government and industry leaders which in some instances has led to potential job opportunities, career advice and helped them develop a greater understanding of the issues related to major infrastructure development associated with ports and how the collaboration between the two countries can provide benefits to each country.

From Australia, a sample of the reflections and comments (verbatim) received from research assistants:

“As I have no proper working experience before, this is the first time in my life I get to apply the knowledge I have learn, especially from management units I took throughout the course such as Management Competences, and Management and Leadership for Engineers.”

“Participating as an RA in Strategic Research Project team 3 has given me exposure to research environment in Australia which I did not expect I would get since I am taking a coursework program in the University of Melbourne. Working on the research, I could see some differences in how Australia and Indonesia develop their infrastructure, such as in the financing options, choosing priorities, public and private sector distribution, etc. However, Indonesia is still developing and Australia is one of the potential countries that will invest in Indonesian development. Therefore, this experience has given me knowledge and insight which I could apply in the future when I am back in Indonesia and get a chance to contribute in projects which are products of Australia-Indonesia collaboration.”

“Although sometimes the works quite time consuming, the RA works has made me more effective in working on my academic assignments and the research works as well.”

“As an awardee of governmental scholarship, this is just exactly what they expect me to do: create a network to build our nation better in the future.”

Some students who worked as RAs on the port study at the UoM welcomed the opportunity to meet with senior port people and academics from Indonesia at the workshop who gave them useful career advice and in some instances offered opportunities for potential future work once they graduate from UoM.

At the conference I met a lot of people from Indonesia and Australia, it was a very good experience to met with this people because I could get some knowledge about how was the port in Indonesia and Australia manage and what problem that they are facing, not only I got knowledge on the port I even got to know the high-level people from Pelindo 2, pt tanjung priok, pt.samudera, etc. the person from pt.pelindo 2 even give me a job opportunity in the pelindo after I graduated from animelb.”

Being involved in the research and the workshop further enhanced the knowledge of the RAs involved and for some gave them a broader perspective of the issues involved and their own approach to projects.

“I was very excited too to see various transportation mode that was suggested from the experts, such as building rail and how truck is more preferable mode of transportation than other. This is new for me, because I never really even care about this stuff. I am starting to develop a thinking model which requires me to see the economical factor behind this preference. As an engineer, I always think that rail will be more efficient and easy for the operation. However, seeing from the shipper perspective, truck is more flexible and cheap, thus they have more control and could customize their activity to satisfy their customer requirements.”

“In conclusion first of all I need to start train my mind to see the helicopter view of a project. Not only the technical issue which is my specialty, but also the business case and other issues.”

“What I get from Prof from UI said that in terms of technology Indonesia is not very too far behind and she said that it’s our job as a younger generation of Indonesia to make our country better.”

“Also, some of the lecturers from Indonesian’s university gave me an advice about my future career and what opportunities that Indonesia might have in the future.”

A number of RAs welcomed the opportunity to work on an actual study dealing with real issues facing their country. They were also encouraged to see the level of engagement and sharing of knowledge that exists between the University research partners and with workshop participants:

“Overall, it was a great learning experience to be part of the research team. I am looking forward being even more involved in the research process and executing the experiments. It will help me further my career and challenge me more for what is to come in my future. This is a real-life experience, involving independence and teamwork, asking for help and giving help, flexibility and meeting deadlines, and great satisfaction.”

“The other things that fascinated me was the way that some experts from both country (Australia & Indonesia) shared their research. I am really happy to witness that knowledge really knows no boundary. People are working together to solve problems based on their experiences and also giving constructive feedbacks to others. I also learned new things about my own country like how they aspire to be a strong maritime country, thus port is one anticipated project to make that goal materialized.”

From Indonesia:

“I have learned much from the professors and researchers at the University of Melbourne during my 10-days stay in Melbourne.”
“This research provided a wonderful opportunity that I never imagine at the beginning as a bachelor student. This project gave me access to some key management persons not just only from the port but also from the high level of government ministry. This truly provided a deep insight to my thesis. Our visit to the Port of Melbourne is a great opening eye for me.”

“One of the most impressive experiences I had was the VICT tour with the Supply Chain & Logistics Association of Australia (SCLAA). VICT is the world’s first terminal with fully automated operations from the gate to the quayside. These automated operations are changing the port landside operation from traditional, manual labor to automatic tasks. It is interesting to see how the automation in port operations is starting to redefine jobs, shifting investment orientation from high labor cost to high tech investment, and how the Australian port industry will deal with this development in the near future.”

“Following discussions, FGD and direct interaction with senior researchers on the topic of freight and port at the University of Melbourne plus a visit to the Victoria International Container Terminal provided me with an extraordinary knowledge of port development and financing in Australia, particularly Melbourne. “

“Opportunities for discussion between the two countries I believe can help to find solutions for transporting goods more efficiently and effectively.”

4.1.2 What the research supervisors say

Anecdotal evidence from the research supervisors has indicated that collaborative research has resulted in positive attitudes observed in students. Students are more willing to invest their time into research especially when they feel that the experience is a real-world experience that can contribute to their careers. The involvement of industry partners means that the problems are not academic paper-based exercises. The contacts made with the high-level delegations from both countries also sharpened the students’ sense of social engagement. The students get to interact with CEO’s and C- level executives which are rare in academic settings. Research supervisors also felt that the collaboration enabled us to do a more in-depth study on the competitiveness of Indonesian and Australian port that might have been difficult if attempted by one party alone. The research also enhanced our understanding on the common problems faced by both countries. It brought up the awareness that universities must work hand-in-hand to improve port competitiveness and to solve problems faced by both countries.

5 Conclusion and Further Research

As demonstrated in our case study of research into large port infrastructure development projects, a good international industry-university collaborative research offers postgraduate students more than just an opportunity to exercise their cognitive and intellectual skills in practicing qualitative and quantitative research methods. The industry collaboration creates a real-world experience where the students can be fully involved. Coupled with research over international borders, the project creates opportunities for students to be intellectually, socially and emotionally engaged with team members from different countries and different disciplines.

6 Acknowledgement

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7 References


Competence development in advanced and emerging construction technologies

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Abstract: Digitalisation is affecting all aspects of the built environment altering the approach in which the design content is conceptualized, project is delivered and buildings are used. This has created a need to provide innovative pathways to successfully equip our next generation of graduates to live up to the challenges of the new competence requirements in the competitive job market. To respond to this demand, presently, Unitec Institute of Technology is developing a new major, 'Technology', in the existing Bachelor of Construction degree, incorporating advanced and emerging construction technologies across the lifecycle of buildings. Simultaneously with the new major development, Construction Informatics and Digital Technology on a broad spectrum are embedded in the existing majors of the Bachelor of Construction and also in the New Zealand Diplomas of Construction and Architectural Technology. This is a natural continuum to the Building Information Modelling (BIM) integration in the programmes. This research focuses on key digital technologies in the curriculum: Green BIM - BIM Building Performance Analysis, Advanced Computational Design, Advanced Construction Technologies and Digital Technologies in Smart Built Environment. The paper argues a holistic approach towards cutting edge digital construction technologies to be taught in interlinked modules and articulates an implementation strategy that allows innovative collaborative approaches to face the challenges of the 21st century and beyond.

Keywords: advanced construction technologies, competence development, construction informatics, curriculum development, digital technologies

1 Introduction

We are currently undergoing the 4th industrial revolution also called Industry 4.0 or Digital revolution (Roblak et al., 2016; Schwab, 2017). Digitalisation is both part of our personal lives through various smart mobile and online technologies and also part of our work, the technologies and their magnitude depending on what industry and company we work at.

Construction industry has traditionally been poor in investing on research and development and because of that also slow in adopting new methods and technology. Digital technology has not been an exception, in fact construction industry is the least digitalised industry sector (Friedrich et al., 2011; Leviakangas, et al., 2017). However, during the past years there have been strong signs of digital technology reaching the industry. With the emergence and development of Building Information Modelling, the construction is being transformed into a realm of digital industry (Azhar et al., 2012; Österreich & Teuteberg, 2016).

Digitalisation means also change in the competences required from the graduates who are entering the industry, which has implications to what tertiary education should deliver. Alongside with the industry, the BIM integration rates have increased also in tertiary education and there has been significant discussion in academic literature on curriculum developments (Abdirad et al., 2016; Barison & Santos, 2010; Becerik-Gerber et al., 2011). There are academic conferences such as BIM Academic Symposia series in the United States and BIM Academic Forum series in the United Kingdom. Various countries have also established national policies for BIM education, Australia, Canada, New Zealand (NZ), the Nordic countries and the United Kingdom (UK) to name a few (Puolitaival et al., 2017). Considering all these, it can be argued that globally there has been a reasonable effort to address the adoption, integration and implementation of BIM into architectural, engineering and construction (AEC) education. Now it is time to continue the journey to discuss more advanced digital technologies. The technologies discussed in this article are Green BIM – BIM and Building Performance Analysis, Advanced Computational Design, Advanced Construction Technologies, and Digital Technologies in Smart Built Environment. The focus subject areas are Construction Management (CM), Quantity Surveying (QS), Property Development (PD) and Architectural Technology (AT).

This research is part of the Stage 2 of the digital technology curriculum development at Unitec Institute of Technology, Auckland, NZ. The article discusses the early part of the Stage 2. When the Stage 1 included integration of BIM into the existing curricula, the Stage 2 includes wider integration of digital technologies into the existing curricula, but more specifically a development of a new major, ‘Technology’, into the existing Bachelor of Construction programme. The overall aim of the Stage 2 research was to achieve a research and industry informed curriculum, to document the development work, and to evaluate the process and the decisions taken to further improve the curriculum. In this article, the key advanced and emerging construction technologies central in the integration are identified and defined using literature. The integration plan, how these technologies are integrated as part of the existing curricula, but more specifically to form a new curriculum (new Technology Major) is described. Developmental action research has been adopted due to its collaborative, evaluative and reflective nature (Zuber-Skerritt & Fletcher, 2007) suitable for a curriculum development of this kind.

2 Advanced and emerging digital technologies

Figure 1. Emerging and advanced technologies knowledge management paradigm in construction

<table>
<thead>
<tr>
<th>Planning and Design</th>
<th>Construction</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digital Technologies in Smart Built Environment</td>
<td>BIM and Building Performance Analysis, Energy Modelling</td>
<td>Mobile Solutions, Augmented Reality</td>
</tr>
<tr>
<td>Green BIM</td>
<td>Advanced Manufacturing, Additive Manufacturing, Design for Manufacture and Assembly (DMA), BIM + BIM Cloud Management, Digital Fabrication, Digital Procurement, Prefabrication, Offsite and Modular Construction, Digital Surveying</td>
<td>Big Data Analytics, Internet of Things (IoT), Digital Infrastructure, Sensors, Robotics</td>
</tr>
</tbody>
</table>

Figure 1. Emerging and advanced technologies knowledge management paradigm in construction
In the following sub-chapters the key advanced and emerging digital technologies are defined using literature, giving also examples of their educational adoption, if applicable. An overview of these technologies is depicted in Figure 1.

2.1 Green BIM - BIM and Building Performance Analysis
Green buildings and structures are rapidly transforming our built environment. The United States Environmental Protection Agency (2018) defines green buildings as a process to construct environmentally responsive and resource-efficient structures and facility resiliency. According to the 2015 Green Building Impact Study by the United States Green Building Council (USGBC), 1.1 million jobs will be contributed by green construction in 2018 (Constructible, 2017). Green BIM is considered as a key technology of building and construction sector in the backdrop of building performance analysis and sustainability (Wong & Zhou, 2015). In simplistic terms it is the use of BIM tools to improve building performance and reach sustainability outcomes. Wu and Issa (2013) observed that Green BIM underpins green outcomes to achieve sustainability in building development through its linkages with BIM. Wong and Zhou (2015) highlight that “green BIM” concept should not be narrowed down to sustainability analysis but it should span entire life cycle of a building. BIM in conjunction with environmental project data ensures project sustainability, optimisation of building energy efficiency, waste management and gives accurate cost and environmental impacts of materials, equipment and technology.

2.2 Advanced Computational Design
Computational thinking (CT) is “the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information processing agent” (Wing, 2010, p.1). It is the process of abstraction, by breaking down and multiple layers of abstract simulations defined in correct relationship in a way that human-machine can easily perform (Kumar, 2017), whereas design thinking tries to comprehend a problem before trying to solve it. In the background of design, computation is the processing of information and interaction between the elements, thus generating a complex order, form and structure (Autodesk, 2018). The connection between architecture, computer science, engineering and construction generates unlimited possibilities for the development of new spaces, products and services using computers for realisation of design. By combining BIM with computational design principles, a new and innovative building design can be created. Similarly, Advanced Computational Design for BIM provides a thorough and detailed process to generate elements by creating and parametrically controlling graphs. As an example, Dynamo is a visual programming open source tool to extend BIM with the data and logic environment, thus creating parametric models (Dynamo, 2018). It is a programming script based on nodes and connected with edges, using data fed as inputs nodes, manipulation of data through various function inside nodes and generating output data (Yang, 2015). Computational design is an open-ended methodology which may involve creating an algorithm to speedily solve repetitive design problems (Barista, 2016).

2.3 Advanced Construction Technologies
Advanced construction technology includes modern techniques and practices that comprise the latest developments and innovations in materials technology, design and construction (designing/buildings, 2017). It entails BIM, additive manufacturing among various other advanced manufacturing technologies, prefabrication and preassembly, robotics, digital surveying, GPS coordinated equipment and smart technology. As this topic area is vast, only some examples are introduced here: Advanced Manufacturing, Design for Manufacturing and Assembly (DfMA) and robotics. Advanced Manufacturing is “family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical and biological sciences, for example nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies.” (Oudekerk et al., 2014, p.1). Design for Manufacturing and Assembly (DfMA) is a design approach having roots in manufacturing that focusses on ease of manufacturing and efficiency of assembly (Wuki et al., 2017) and enable processes where buildings are designed for the ease off-site manufacturing and efficiency of on-site assembly. The advantages accrued include speed of construction through use of prefabricated elements, lower assembly cost by decreasing amount of labour and parts, higher quality and sustainability by speeding up the logistic chain, shorter assembly time and increased reliability and safety. DfMA is a catalyst for creativity and innovation and is the future of construction in terms of parametrically designing, integrated products, whole life performance of buildings and infrastructure, potential to maintain, refurbish, disassemble, recycle and re-use built assets (Davies, 2013). The demands of modern day construction in terms of short design and build, high quality and low cost can be realised through flexible automation using robots which can assist as an example in masonry prefabrication, pre cast concrete, timber construction and steel component production (Bock, 2015).

2.4 Digital Technologies in Smart Built Environment
With the proliferation of Information Technology, Artificial Intelligence and Machine learning, data play a key role in decision making process in smart built environment within a context of intelligent buildings, smart communities and cities (IET, n.d.). Big data refers to a large collection of data sets from multiple sources whereas Data Analytics denotes processing mechanisms, techniques and methods to analyse and interpret the datasets for extracting meaningful intelligence. In construction, examples of big data use are such as environmental data, stakeholder input and social media discussions, which can be used to determine what and where to build; Big data from traffic, weather, community, onsite sensors and machines can be used for precise phasing of construction activities, using fuel, buying and leasing of equipment and improving logistics; and data is fed back into BIM systems for maintenance of buildings (Burger, 2017). Internet of Things (IoT) on the other hand has a significant role in building energy management systems, building control algorithms, space utilisation, service monitoring, and communication with mobile devices (Weems, 2018). In smart cities, 1.6 billion IoT components and devices were employed in 2017, 39% increase compared to 2015. IoT becomes an instance of cyber physical systems, intelligent infrastructure and smart homes and cities when used in conjunction with sensors and actuators (Tiwary et al., 2018). Moreover, immersive technologies of Virtual, Augmented and Mixed Reality (VAMR) are gaining significance in AEC industry. Cloud computing can be seen to belong to this group as well. It is yet another transformational force for innovative use of ICT. As an example, cloud BIM is being considered as second generation of BIM development and another game changer for construction industry (Wong et al., 2014). These technologies in combination with BIM have significant applications in construction industry including visualisation, construction safety, and integrated planning among others (Li et al., 2018; Mohamed et al., 2018).
2.5 Advanced and emerging technologies in educational context

There are some examples of the application of Green BIM in educational context such as Kim (2015) exploring the effectiveness of Green BIM teaching method, Hyatt (2011) with integration of Lean construction, Green and BIM into an undergraduate construction management course, and Wu and Luo (2015) investigating the synergies of sustainability and BIM through collaborative project-based learning. Digital fabrication has also been addressed quite well in the educational context (Becerik-Geber et al., 2011), but there is a limited amount, if any literature on Advanced Computational Design and Digital Technologies in Smart Built Environment education.

3 Research Methodology

3.1 Research context

3.1.1 Digital technology integration at Unitec

The Construction Management discipline at Unitec delivers four undergraduate programmes in the subject areas of Architectural Technology, Construction Management, Property Development and Quantity Surveying. The initial investigation and decision to include BIM as part of the programmes was made in 2009. At this time BIM had not yet gained momentum in NZ, but the discipline strongly believed that BIM would be the way also for the construction industry in NZ. Since 2009 there has been several investigations, such as literature studies on existing BIM curricula, learning outcomes, teaching, learning and appropriate assessment methods for BIM and empirical testing, and evaluation of the Unitec’s BIM integration framework as a whole (Puolitaival & Forsythe, 2016). This part is referred to as Stage 1. The integration has been and will be continuous, monitoring and following the pace the NZ construction industry is adopting and implementing BIM, aiming to be at the same level with the leading practices in the industry to guarantee the graduates the most current and relevant competences. When the industry nationally and internationally is moving from the initial implementation of BIM to more advanced uses of digital technologies, Unitec is taking the steps with them. This is referred to as Stage 2.

2.5.1 Programme development of a new Technology major at Unitec

Like many other developed countries, New Zealand has a national qualifications system that uses a framework of learning ‘levels’ and ‘credits’ (New Zealand Government, 2016). The output of a qualification is expressed by coherent collections of outcome statements. These outcomes are independent of any particular learning pathway; achievement of the outcomes is demonstrated by assessment (Young & Matseleng, 2013). The top level of outcomes for a qualification are expressed in a ‘graduate profile’. The collections of subsidiary outcomes, contained within its modules (‘papers’ or ‘courses’), must progress to the graduate outcomes in a manner that is pedagogically sound, and sensible. The modules of learning at Unitec are termed ‘courses’ and they each bear 15 credits at a designated level. A two-year diploma contains 16 courses and a three-year degree contains 24 courses. The written aims and learning outcomes of the individual courses are the mechanisms by which the learning journey through a particular topic area in construction studies is defined and progressed towards the final graduate outcomes. This progression is more obvious and understandable for subjects like language or mathematical competencies. Learning progression through emerging construction technologies is less obvious and involves revisiting topic areas for further development and insights, as in the integration of BIM. Another tension in the curriculum development process for any advanced and emerging technology is to define outcomes with enough rigour to satisfy accreditation authorities yet, at the same time, to leave the outcomes open enough to accommodate the study or technologies not yet emerged, or even named. The process is helped by the use of general learning descriptors for a particular framework level. For progression between qualifications, such as from a diploma to a degree, the ‘neatest’ arrangement is for the two programmes to have overlapping courses with the same specifications.

2.6 Research approach

As explained above, this research is part of the next development stage of the digital technology curriculum development at Unitec. This Stage 2 includes wider integration of digital technologies into the existing curricula, but more specifically a development of a new major, ‘Technology’, into the existing Bachelor of Construction programme. With this background the same research approach as with the Stage 1, developmental action research, has been adopted. The full context and research methodology of the Stage 1 is described in ‘Practical challenges of BIM education’ by Puolitaival and Forsythe (2016). In brief, the Stage 1 was fully about integration of BIM as part of a number of Architectural Technology, Construction Management and Quantity Surveying courses to ensure that the graduates from these subject areas would have a good set of subject area specific BIM skills and knowledge to meet the industry needs (Puolitaival & Forsythe, 2016). At course level 5 basics of BIM were introduced and at levels 6 and 7 gradually the content moved from subject area specific basic concepts to more advanced use of BIM. The integration has included both diploma (level 6) and degree (level 7) level programmes. There is a pathway from the level 6 programmes to level 7 ones. The development work was documented and the BIM framework was tested in action.

Developmental action research is suitable to the social phenomena under investigation offering a collaborative, reflective, accountable, self-evaluative and participative involvement (Zuber-Skerrit & Fletcher, 2007). Action research is known to be well suited and useful in educational settings due to its nature offering problem identification, action planning, implementation, evaluation, and reflection (Groves & Zemel, 2000). This article discusses the early parts of the Stage 2. The key advanced and emerging construction technologies central in the integration are identified and defined in chapter 2 using literature. The integration plan, how these technologies are integrated as part of the existing curricula, but more specifically to form the new curriculum (new Technology major) is described in chapter 4.

4 Findings and Discussion

The Stage 2 is looking into Green BIM, Advanced Computational Design, Advanced Construction Technologies, and Digital Technologies in Smart Built Environment as the key groups of digital technologies to be integrated into the curriculum. In figure 2 the Stage 2 integration to some of the existing Bachelor of Construction courses is identified alongside the inclusion of these topics in the new courses to be developed for the new Technology major. The integration will also cover similar courses at the diploma level.
The proposed articulation of Green BIM within the curriculum will deliver advanced and state of the art sustainability knowledge to understand the building performance analysis throughout its life cycle from site analysis to energy loads, daylighting, sun and shadows, solar radiations, climate analysis, ventilations, air flow analysis to whole building energy analysis. The approach commences with the BIM-based teaching method developed in earlier courses similarly to Wu and Luo (2015) and further encompassing knowledge of sustainability in a built environment. Green BIM will be integrated at level 6 to Sustainable Design and Construction Course and Virtual Design and Construction 2, and at level 7 to Technologies in Practice and Building Performance courses in the new Technology Major.

Advanced Computational Design prepares students for continuing advancement of technological and computational processes coupling a basic introductory analytical approach to computation, design and fabrication simulation. It is integrated as part of the Virtual Design and Construction 2 and Technologies in Practice courses.

Advanced Construction Technologies lends its name to one of the courses in the new Technology Major, but these technologies: digital fabrication, additive manufacturing, off site manufacturing, digital surveying, robotics and GPS controlled equipment as an example, will be integrated also to other courses in the programme where appropriate (Figure 2). The challenge with this technology is how to create opportunities for practical learning, when the technology is mostly relying on heavy and fast developing equipment, which are out of reach by most educational institutes (McAvoygroup, 2017)

Understanding enablers, opportunities and challenges in Digital Technologies in Smart Built Environment domain is utmost important for fresh graduates to ensure appropriate investments of resources in and getting the most out from the digital built environment projects (IET, n.d.). This topic will have a place in multiple courses across the majors, but the most emphasis in Advanced BIM in Construction and Technologies in Practice courses.

5 Conclusion and Further Research

This research is part of the Stage 2 of the digital technology curriculum development at Unitec Institute of Technology, Auckland, NZ. For the Stage 2 developmental action research has been adopted due to its collaborative, evaluative and reflective nature. In this article, the key advanced and emerging construction technologies have been identified and defined using literature, and the integration plan has been discussed.

The key digital technologies are: Green BIM - BIM Building Performance Analysis, Advanced Computational Design, Advanced Construction Technologies and Digital Technologies in Smart Built Environment. These technologies are integrated to the courses to form the core of the new Technology major in the Bachelor of Construction programme, but they are also integrated as part of the existing Architectural Technology, Construction Management, Property Development and Quantity Surveying curricula at levels 6 and 7.

This research contributes to the knowledge of understanding what advances these key digital technologies can bring to the construction industry, but most importantly what technologies are an appropriate fit with undergraduate courses in architectural technology, construction management, property development and quantity surveying, and how they can be integrated as part of the curriculum.

The next steps of the research are industry and faculty surveys to continue the industry consultation to inform the detailed curriculum development and to develop appropriate and efficient ways to deliver and assess the content, and finally empirical testing and evaluation of the curriculum.

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The status of offsite construction in Vietnam

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Abstract:
There are key advantages attributable to offsite construction but developing countries such as Vietnam are facing many challenges. Despite its importance, there is scant evidence and review of this in Vietnam. This paucity of research does not stem from lack of interest in the topic, but from the scarcity of relevant information and as an alien subject in Vietnam. This study aims to provide a detailed insight into the offsite construction and to develop a strategic roadmap for its propagation in the Vietnamese construction industry. This upstream analytical paper reviews offsite construction in Vietnam and abroad, recalls differences between “offsite construction” with its siblings of “modular” and “prefabrication”, then formulates possible barriers, drivers, and success factors to offsite solutions. The research involves eliciting expert opinion through eight in-depth face-to-face interviews. These geographically relate to Hanoi and Ho Chi Minh City which are administrative and commercial centers respectively. Interviews were conducted with Vietnamese government officials, investors, and professionals seeking their informed judgment. Saturation method was applied for qualitative hypotheses formulation. The qualitative data analysis based on expert interviews generates several key findings. All respondents expressed their concern about barriers to modular construction being inactive; however, considering the new Circular 13/2017/TT-BXD that restricts the use of “baked” building materials, expected greater adoption of offsite construction. The main reasons for difficulties of Vietnamese prefabrication include the settings of a regulatory framework, the bias and reluctance to change, and the technological retrofit. Correlation between categories will be also accounted for in the study.

Keywords:
Offsite construction, Construction Industry, Offsite manufacturing, Prefabrication, Modularisation

1. Introduction

This research aims to develop a strategic roadmap for propagation of Offsite Construction (OSC) in the Vietnamese Construction Industry. Three objectives are set for the whole study: (a) to explore perceived barriers to OSC: because too little research is found out about OSC in Vietnam, the first objective is to solicit professional insights and to investigate possible barriers under the form of hypotheses; (b) to confirm the causal relationship for targeted audience: hypotheses will be tested by SPSS then ranked with respective confidence level. “Theory-after” approach is hereby adopted. This diagnostic quantitative process will be demonstrated at another paper; and (c) to define a specific roadmap to help OSC in Vietnam. This problem-solving approach is twofold: to recommend optimum solutions for improvement of OSC, and to guide through measurement and control during the implementation process.

In order to meet the aims and objectives, specific boundaries are identified: (a) Key Theoretic Issue is placed on the feasibility conditions to develop Offsite Construction to Vietnam, rather than discovering new scientific formulas or engineering theories; (b) Research Context opens to big cities in Vietnam like Hanoi and Ho Chi Minh City; (c) Analytic Focus probes enterprise development and joint venture opportunities; and (d) Targeted audience includes manufacturers, general contractors, consultants, investors and developers, and government officials.

2. Literature Review

2.1 Offsite Construction and its siblings

Many terms have been mentioned for the “offsite family” and used interchangeably, which includes Off-Site Production, Off-Site Fabrication, Off-Site Manufacturing, Off-Site Construction, Pre-assembly, Prefabrication, Industrialized Building (Goodier & Gibb, 2005; Wei, Gibb & Dainty, 2012; Anuar & Abb, 2011). Differences between manufacturing and construction were defined on the basis of site location, product life span, product characteristics, location of tasks, work environment, size of product (Nadim & Goulding, 2011). Offsite Construction has received attention since 1998 and became more popular by 2003 (Taylor, 2010). It denotes a technical process where part of the works is prefabricated away from the construction site prior to installation in their designated positions. Definitions of Offsite Construction were presented in details by BuildOffsite (Gibb & Pendlebury, 2006b) together with a glossary of various terms.

2.2 Generalities of Offsite Construction

The concept of prefabrication originated from many years ago by nomadic peoples on the move establishing dwelling. Since the 19th century, the last recession played a critical factor for prefabrication to blossom. The shortage of labourers, in coincidence with the need for increased efficiency, made prefabrication a prominent solution (Staib, Dornhofer, & Rosenthal, 2008). The primary purpose of prefabrication is to offset some of the construction works to better-controlled conditions and manufacturing premises (Arif & Egbo, 2010; cited in Goulding, Rahimian, Arif & Sharp, 2015, p. 163). Recent studies (Lawson, Ogden & Goodier, 2014; BuildOffsite, 2006b; Gibb, 1999) have classified the offsite construction technologies into four levels: (1) manufactured components followed by site-intensive construction; (2) linear or 2D manufactured assemblies initially promoted throughout the 1950’s and 1960’s; (3) 3D volumetric modules as major parts of building initiated during the 1960’s and 70’s; and (4) complete building systems starting at the end of the 20th century and comprising modules that are substantially finished before transporting and installing to their final positions on site. Modular Construction is at level four (4) with up to 70% of the construction work prefabricated under three-dimensional modules or volumetric assemblies in factories (Lawson, Ogden, & Goodier, 2014; Kamali & Hewage, 2016).

Numerous researchers have studied and published articles on offsite advantages. Tatum et al. (1987) noted that modular construction offers an opportunity to improve project performance by improving constructability. Choi, O’Connor and Kim (2016) supported the views of Haas et al. (2000; cited in Choi, O’Connor and Kim, 2016) that prefabrication can lead to improvements in productivity and safety performance with lower labor costs. Lawson, Ogden and Goodier (2014) reported that the key advantages of modular construction may include: shorter build times, better quality control achieved by factory-based advantages, enhanced economy of scale in production, better
health and safety control, reduced labor costs. Goodier and Gibb (2007) organized a prOSpa survey in UK and revealed that the biggest advantages of offsite construction compared to traditional method are: (1st) decreased construction time on site, (2nd) increased quality, (3rd) more consistent product, (4th) reduced snagging and defects, and (5th) increased value.

Fussel, Blismas et al., (2007) reported that a natural dialectic in offsite construction exists between volume and choice. Modularization and economies of scale have limited customer choice. Goulding et al. (2015) noted that “offsite construction takes a small proportion of construction activity in both developed and developing countries.” They recalled that offsite construction has not yet been propagated in Hong Kong’s private sector projects (Jaillon & Poon, 2009); in the UK, the market share is only around 6% (Taylor, 2009) and approximately 7% in USA (HAC, 2011; cited in Goulding, Rahimian, Arif & Sharp (2015, p. 164)). According to Goulding et al., offsite construction disadvantages may stem from: (a) lack of synchronization between design technology and disciplines, (b) shortage of production flexibility, (c) the need for a better approach to customer desires, and (d) concurrent engineering. Forbes-Julia Bunch-2017 remarked that one downside to offsite construction is the reduced flexibility to update buildings in the field.

2.3 The notion of drivers of, barriers to, and success factors for offsite construction

Drivers: “Who usually drives the idea of using offsite” is an important question. In UK, a survey indicates that main drivers of offsite construction on a project stem from: (1st) contractor/architect (85% of respondents), (2nd) client (75%), (3rd) designer (70%), (4th) OSP manufacturers (55%), and (5th) statutory authorities (45% respondents); (Goodier & Gibb, 2005, p. 154). In Malaysia, the most important drivers for contractors to use Industrialized Building Systems are: (1st) achieving high quality (13.36%), (2nd) gaining speed of construction (12.93%), (3rd) client demand (8.62%), and (4th) addressing skill shortage (7.33%); (Anuar, Nawi, & M.N.A., 2014, p. 494).

Barriers: A general consensus from many researchers is that off-site technologies should be considered in the early design stages (Wei, Gibb, & Dainty, 2012). Pasquaire and Gibb (2002), and Fussel et al. (2007, p. 13) all pinpointed that the use of OSM is inadequately understood by many stakeholders focusing on anecdotal rather than data-driven reasoning. Similarly, Goodier and Gibb (2005) concluded from their survey that less than a third of the interviewees in UK thought that their customers were aware of the relative advantages and disadvantages of offsite over traditional construction. Cognitive perception and bias also participate as barriers to OSC. Goodier and Gibb (2007) reported that “many house buyers are so strongly influenced by negative perceptions of post-war prefabrication.” Resistance to change and the negative image of offsite become two emerging barriers in many recent surveys (Samuelsson Brown et al., 2003; Venables et al., 2004; RGU, 2002; cited in Chris Goodier & Alistair Gibb, 2007). Goodier and Gibb (2007, p. 588) organized surveys in UK and came up with perceived barriers hindering the increased use of offsite construction: (1) more expensive, (2) longer lead-in times, (3) client resistance, (4) lack of guidance & info, (5) increased risk, (6) few codes/standards available, (7) negative image.

Success Factors: Babatunde and Perera (2015) have studied about success factors: the concept of Critical Success Factors (CSF) was first used by information systems and project management by Rockart (1982) and the Sloan School of Management (Jeffries et al., 2002). Rockart (1982) explained Critical Success Factors as those limited areas where “things must go right” for a particular business to survive. Kwak et al., (2009) described CSFs as “few key areas in which satisfactory results are necessary to ensuring successful competitive performance for the organization.” Ram and Corkindale (2014) argued that CSFs require the constant and careful attention of management with a view to achieving organizational performance goals.

Gibb and Isack (2003) identified several success factors for offsite construction as early design freeze, sufficient time for prototyping, and the owner’s understanding of benefits and limitations. Acknowledging those success factors from early consideration (Burke & Miller, 1998; Post 2010) to subsequent studies, O’Connor et al. (2014) identified 21 CSFs for modular success (Choi, O’Connor, & Kim, 2016). A recent survey in Malaysia introduced Critical Success Factors Ranking (Anuar, Nawi, & M.N.A., 2014, p.496); from which, five top influencers include: (1st) Top-Down vision and commitment, (2nd) Early decision to use IBS, (3rd) Early assembly of project team, (4th) Effective communication, (5th) Site, logistics and machineries.

2.4 Offsite Construction in the International Context

In order to “shift the dependence on labor towards a knowledge-based industry”, offsite production was appointed as a potential solution (Barker, 2003; Manu Build, 2009; cited in Nadim & Goulding, 2011). The value of the UK offsite market was estimated at £2.2bn in 2004 (Chris Goodier & Gibb, 2007). However, Gibb and Goodier (2004b) found it “extremely difficult” to obtain the true proportion of offsite which is imported or exported (Blismas & Wakefield, 2007). In Sweden, approximately 74 percent (between 1990 and 2002) of the detached single houses are still manufactured in permanent factories (Bergstrom & Stehn, 2005; cited in Segerstedt & Olofsson, 2010). A major hindrance to the introduction of offsite construction is how to synchronize between industrialized building constraints and the traditional designing-building being rooted for long time (Anderson et al., 2009; cited in Segerstedt & Olofsson, 2010). Despite the documented benefits of offsite construction, its applications are still limited in America. The US modular industry accounts for only 2-3% of the total new single-family houses and equal or less than 1% of the total new multi-family houses between 2000 and 2014 (Characteristics of new housing; Report, Washington, DC, USA: US Census Bureau; 2016). A main reason is the difficulty in perceiving its potential benefits, judged from anecdotal evidence rather than rigorous data (Kamali & Hewaye, 2016).

In China, key challenges to prefabrication included lack of manufacturing capability, product quality problems, and lack of supply chain (Arif & Egbo, 2010; cited in Mostafa, Dumrak, Chileshe & Zuo, 2014). In Malaysia, the government has stimulated Industrialized Building Systems through government projects (Mus, Mohd, Yusof, & Rofliizan, 2016) and has established IBS legislation and codes (Mostafa et al., 2014). However, IBS Mid Term Review in 2007 summarized that only 10% of the completed projects used IBS in 2006 (Hamid et al., 2008; cited in Anuar, Kamar, Hamid & Alshawi, 2010). High initial capital investment and lack of technical expertise are among the obstacles to IBS in Malaysia (Mohammad F. Mohammad et al., 2015). In India, the India Concept House (ICH) represents construction of affordable housing using prefabricated technology (Mostafa et al., 2014). In Nigeria, Kolo et al. (2014) reported that new barriers to OSM include “reluctance to innovate, paucity of codes and standards, supply chain integrations, and skill requirements” (Mohammad F. Mohammad et al., 2015). There is a need for greater awareness and encouragement from the Government (Rahimiana et al., 2017).
In Australia, the Australian construction industry has recently identified offsite manufacture as a key vision for improving the industry (Hampson & Brandon, 2004). According to Blismas et al. (2007), the first five drivers and benefits of offsite manufacturing include: (1st) reduce construction time; (2nd) simplify construction processes; (3rd) provide higher quality, better control and more consistency; (4th) reduce costs when resources are scarce, or in remote areas; and (5th) result in improved working conditions. Despite its benefits, uptake of OSM in Australia remains limited by the lack of collaboration across the fragmented housing construction sector (Pablo, London, & Wong, 2017). Besides, Australia has no industry peak body or association, apart from groups such as the National Precast Concrete Association, which represents offsite manufacturers as does the US or UK (Blismas & Wakefield, 2007).

2.5 Offsite Construction in Vietnam

With the boost from 2014 Housing Law, Vietnam real estate market is starting to warm up which, in turn, supports the recovery of residential construction sector. Shown on a report by Davis Langdon & Seah (cited in FPTS, 2015, p. 22), construction costs in Vietnam are relatively lower than most of other Asian countries within the same categories. Regarding the causal relationship in the Vietnam construction, a research by Nguyen et al. (2004) revealed that top-ranked problems in terms of occurrence derive from five factors: (1) incompetent designers/contractors, (2) poor estimation and change management, (3) social and technological issues, (4) site related issues, and (5) improper techniques and tools. “Problems attributable to owners and the environment were perceived not to be as important in occurrence as their influence on performance is. Problems attributed to financiers and project attributes were rated low both for occurrence and influence” (Nguyen et al., 2004). Nguyen and Chileshe (2013) appointed most critical factors causing the failure of construction projects in Vietnam as: (1) “disregard of the significance of project planning process”, (2) “lack of experimental and executing complicated project”, (3) “poor design capacity and frequent design changes”, (4) “lack of knowledge and ability in managing construction projects”, and (5) “lack of financial capacity of owner”.

Prefabrication was adopted thousand years ago with different traditional technologies such as prefabricated moveable thatched roofs in Ethiopia, Vietnam or Mexico or bamboo panels in Asian architecture (Stallen, Chabannest, & Steinberg, 1994). Currently, “residential and infrastructure sectors always occupy for the highest percentage in the industry structure; in which, infrastructure construction takes 41.2% of total output, residential construction accounts for 40.6%” (FPTS, 2015). Recently, the Vietnam government has promulgated the Circular 13/2017/TT-BXD stipulating that all buildings from 9-storey and above must consist of at least 70% of unburned building materials, which include autoclaved aerated concrete brick and light-weight concrete. This Decision is likely to vivify the tacit offsite facet in purpose.

3. Research Methodology

3.1. Research Strategies

Axinn, Pearce (2006, p. 20) and Cooper, Schindler (2014, p. 129) pinpointed both qualitative and quantitative for exploratory studies. However, the dilemma is “which method should come first?” Tracy (2013; p. 5, 25) posited that qualitative approach should start exploring for high degree of richness that will be subsequently tested by structured questionnaires. Similarly, Jonker and Pennink (2010, p. 90) ascertained that the outcomes from qualitative research should be followed by a quantitative approach. This sequence was also applied by Goodier and Gibb (2007) organized a program following the order of: (1st) literature review, (2nd) qualitative exploration of six organizations, (3rd) quantitative survey of UK entities, and (4th) Steering Committee workshop. To our opinion, Goodier and Gibb’s process was highly objective by first soliciting – without purposive direction from the researchers – qualitative insights of professionals, then using quantitative survey to confirm hypotheses. If quantitative close-end questions were introduced first, the respondents would receive less freedom for ideas and their outcomes would be inevitably framed along the conduit of those questionnaires. In brief, conforming to all the above coincidences, the methodology for this study of OSC in Vietnam (upstream) comprises literature review and qualitative experiment. Such qualitative generation output from this paper is a set of Perceived Barriers – that will be tested in large scale by another next paper (midstream) to come up finally with Success Factors.

3.2. Research Methods

Regarding the constitution of qualitative interviews, Cooper and Schindler (2014, p. 126) advocated that exploratory studies use loose structures with the aim of continuing future research tasks. The less-structured interviews appear less artificial than a structured interview and more resemble a conversation between equal participants (Sapsford & Jupp, 2006, p. 95). Regarding success factors – one of the aims of this research into OSC in Vietnam – Rockart and Bullen (1981) and Howell (2010) rely on data collection. The best technique for collecting data appoints interviewing personnel “one-on-one, using already developed open-ended questions” (Howell, 2010, p. 20). With the same viewpoint, Grunert and Ellegaard (1992) ascertained that success factors can also be measured by semi-structured interviews and ladder procedures.

This study splits the interviewees into non-overlapping clusters: (a) Stakeholders including government officials, investors and professionals; and (b) Geographic zoning. Non-probability sampling with preliminary judgment (purposive) was applied. Interviews were conducted one-by-one at the informants’ workplaces in Hanoi and Ho Chi Minh City, face-to-face to record nonverbal and verbal behaviour. Saturation was applied to refer to the point at which the data became repetitive and no major new insights were gained. During the interviews, shorthand recorded data. Three generative questions were initiated during the interviews:

• What do you think about the offsite construction in Vietnam?
• What are the perceived barriers to offsite construction in Vietnam?
• How to improve the situation?

4. Findings and Discussion

Nguyen and Panuwatwannich (no date) organized a case study comparison between one traditional project construction method and one BubbleDeck/3D-panel wall technique simulation. From such a single case and questionnaire, the study affirmed that “approximately 80% of the key figures in the Vietnamese construction industry are convinced that the design-for-manufacture techniques could be popular in Vietnam” (Nguyen & Panuwatwannich, n.d., p. 2, italics); [then reiterated that “the exploratory study further showed a strong confidence that the design-for-manufacture techniques would be popular in the country” (Nguyen & Panuwatwannich, n.d., p. 7, italics). The conclusion emphasised: “the case study demonstrated that the design-for-manufacture
techniques provided better results than traditional construction methods” (Nguyen & Panuwatwanich, n.d., p. 8, italics). Considering the above-mentioned research method, readers may not be able to visualise the correlations between their case study (BubbleDeck) and its questionnaire sent to experts: Was the survey restricted to case-study only or was the questionnaire expanding to the national offsite industry?

Regarding potential barriers, Nguyen and Panuwatwanich (n.d., p. 2) described that “some critical barriers affecting the selection of these techniques were identified, including cost, lack of knowledge, conservatism/negativism, lack of evaluation tools and lack of available suppliers.”

This study of OSC in Vietnam is ending here with perceived barriers deriving from expert qualitative interviews. Such findings are summarized on Table 1.

Table 1: Summary of Barriers as Perceived by Vietnamese Experts Interviews

<table>
<thead>
<tr>
<th>PERCEIVED BARRIERS TO OSC BY INTERVIEWEES</th>
<th>GOV HCM</th>
<th>GOV HAN</th>
<th>GOV PRJ</th>
<th>CEO R Est</th>
<th>Exp</th>
<th>GD</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Respondents' admittance of advantages of OSC</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>OSC in Vietnam is facing serious difficulties</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Fragmentation: concrete piles, shoring, beams</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segmentation/ life-cycles: land, equip.,machinery import, direct-assembling, mobilization</td>
<td>x</td>
<td>x</td>
<td></td>
<td>33</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lack of synchronization between design, manufacturing and execution</td>
<td>x</td>
<td>x</td>
<td></td>
<td>33</td>
<td></td>
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<td></td>
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<tr>
<td>Excessive differentiation in residential designs</td>
<td>x</td>
<td>x</td>
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<td>33</td>
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<td></td>
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<tr>
<td>Technology &amp; Knowledge</td>
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<tr>
<td>Lack of knowledge of OSM</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>OSC technology being taken for short-term only</td>
<td>x</td>
<td></td>
<td>x</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Technological advantages not demonstrated “realistic” to stakeholders</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>50</td>
<td></td>
<td></td>
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<tr>
<td>Investment</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>VN investors too small, not enough to standardize</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lack of potential investors that update technology, open market share and applicability</td>
<td>x</td>
<td>x</td>
<td></td>
<td>33</td>
<td></td>
<td></td>
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<tr>
<td>Scales and quantities not large enough for standardization and cost reduction</td>
<td>x</td>
<td>x</td>
<td></td>
<td>33</td>
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<tr>
<td>Design &amp; Norms</td>
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<tr>
<td>Architectural richness restricted by modularization</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
<td></td>
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<tr>
<td>No design competition to alleviate monotony</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lack of standards, calculations, calibration &amp; rates</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>100</td>
<td></td>
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<tr>
<td>Lack of reference to and adoption of standards and norms from advanced countries</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>67</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Lack of synchronization between design disciplines</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Government Strategy</td>
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<tr>
<td>Lack of Government direct support (approval, regulations, etc.)</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Government indirect incentives and motivation for society to develop OSC by self</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Land fragmentation due to approvals of small projects</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
<td></td>
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<tr>
<td>Lack of big cities (like Korea) with big scale housing but limited settings of standardized design</td>
<td>x</td>
<td></td>
<td></td>
<td>17</td>
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<td></td>
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<tr>
<td>Association</td>
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<tr>
<td>No official bodies to communicate OSC applicability and initiatives</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>50</td>
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</tbody>
</table>

5. Conclusion and Further Research

The literature review of this study and qualitative interviews result in targeted outcomes, namely as perceived barriers to offshore construction in Vietnam. Emerging barriers include: (1) Lack of standards, norms, calculations, calibration and unit rates for OSC; (2a) Lack of knowledge of OSC; (2b) Stakeholders’ reluctance to new ideas and changes; (2c) Lack of understanding and acceptance by tenants, customers; (2d) Lack of advertising campaign to change people mindset; (2f) Lack of Government direct support; (2f) Lack of reference to and adoption of standards and norms from advanced countries; (3a) No official bodies to communicate OSC applicability and initiatives; (3b) VN investors too small, not enough to standardize assemblies; (3c) Lack of vocational training for molding, assembling big panels, and transportation.

Explicitly beneficial to the scant literature and review of the offshore construction in Vietnam, this paper (upstream) is adding notions and unbiased generalization of perceived barriers. By solving the paucity of information, this study also delineates causal factors to help the local construction industry. Next paper (midstream) will bring such barriers to testing-out for clarifying success factors. Final paper (downstream) will crop well with solutions for the Vietnamese offshore construction to revitalize and with openings for multilateral stimulation.

As part of implicit benefits, relevance of this research is projected to satisfy the extended audience including practitioners and general public “flagging” their needs for and interests in these papers. Moreover, significance of this study justifies itself by intriguing the audience with unprejudiced initiatives and wealthy conviction and by soliciting future researchers into the same topic.
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An ontology of control measures for fall from height in the construction industry

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Abstract:
Fall from heights (FFH) has been a major contributor towards both minor and major work-related injuries in the construction industry. In order to facilitate knowledge reuse/sharing and the development of knowledge-based systems for working at height, this paper aims to develop a lightweight ontology of control measures for fall from height (FFH) in the construction industry. The fall-from-heights ontology (FFH-Onto) is developed based on a generic ontological framework which consists of nine concepts: actor, task, building element, hazard, construction method, constraint, safety resource, hazard control measure, and residual risk. These nine concepts are categorized into three main parts: problem, context, and solution. The FFH-Onto can be used to facilitate knowledge reuse and sharing among the end-users (e.g., designer, engineer, safety professional, supervisor, and site manager). It forms an important basis for developing knowledge-based systems for automated and intelligent fall protection engineering and management in the construction industry. Future efforts can be made to upgrade the proposed lightweight ontology to a heavyweight one which includes axioms and constraints. In addition, ontologies of other key hazards (e.g., struck by objects) are to be developed.

Keywords: Construction safety, fall from height, ontology, knowledge engineering

1 Introduction

While the overall safety performance in the construction industry has improved over the past decades, fall accidents and injuries in some countries have increased (Bobick 2004). Fall from heights (FFH) has been a major contributor towards both minor and major work-related injuries in the construction industry of many countries and regions, such as Singapore (OHSE, 1998; WSIC, 2016), UK (HSE, 2015), US (Bobick 2004), Hong Kong (Law et al. 2016). For example, FFH accounted for over 20% of the major injuries in Singapore workplaces over the past five years. To prevent or control the effect of a fall, a combination of control measures is often adopted. Based on the hierarchy of control (Guo and Goh 2017), the control measures usually include elimination, substitution, engineering controls, administrative controls, and personal protection equipment (PPE). A large number of work-at-height (Wah) standards, best-practice, and guidelines were developed to help key stakeholders manage fall hazards on sites. However, similar fall injuries constantly occur (Goh and Love 2010; Hu et al. 2011). This is in part attributed to the fact that control measures for fall hazards are often not well designed and implemented and the information/knowledge is not communicated to workers. Due to the highly fragmented construction environment, lack of safety knowledge sharing and reuse is another critical reason for high fall accident rates (Ulang et al. 2009).

Last two decades have seen a rapid growth in the use of Building Information Modeling (BIM) to facilitate communication, collaboration, and cooperation between key stakeholders of a construction project. Different information is integrated into BIM models for better cost management, scheduling, and facility management. However, the integration of safety information (e.g., fall hazard and control measures) into BIM models has been rather limited. Current safety practices are largely manual, paper-based, and therefore time-consuming and highly inefficient.

The integration of safety into BIM requires a formal knowledge base of construction safety domain. Developing an ontology is often considered an important starting point to construct the knowledge base (Trausan-Matu 2011). The concept of “ontology” comes from philosophy, which is concerned with the nature of being and existence (Guo and Goh 2017). Gruber provided a popular definition of ontology: an ontology is an ‘explicit specification of a conceptualization’ (Gruber 1995) (p. 908). A “conceptualization” refers to an abstract model of a domain of interest based on relevant concepts, relations, and axioms within the domain. Ontology is an important means for knowledge representation, interoperability, and integration. It often plays key roles in the development of knowledge base and intelligent systems. The previous effort was made to develop an ontology for the design of active fall protection system (AFPS) (Guo and Goh 2017). Note that AFPS is only a part of control measures for fall hazards. There is no common ontology describing the knowledge of the domain of FFH in the construction industry and therefore more effort is needed to develop a more comprehensive ontology for fall from the height by incorporating other fall control measures.

Thus, this paper aims to develop a lightweight ontology of control measures for fall from height in the construction industry. According to Gomez-Perez et al. (2006), lightweight ontologies only include concepts, concept taxonomies, relationships between concepts, and properties that describe concepts. An ontology must formally represent the domain knowledge that can serve its purposes. In this study, a main purpose of the FFH-Onto is to facilitate the selection, implementation, and maintenance of fall hazard controls. It also aims to facilitate the modeling and visualization of fall hazard controls in building information models and thus improve safety engineering and planning.

2 Literature Review

Fall from height has received significant attention from researchers in the construction industry. For example, Huang and Hinze (2003) investigated the root causes of fall accidents based on the data from OSHA. A number of contributing factors were identified, including lack of safety training, human error, and inappropriate use of controls. Similarly, Chan et al. (2008) identified twelve common contributing factors by analyzing twenty-two fall injuries in Hong Kong. They suggested five strategies reduce fall accidents, including (1) provide and maintain a safe system of work, (2) provide a suitable working platform, (3) provide safety information, training, instruction, and supervision, (4) provide suitable fall arresting system/anchorage; and (5) maintain safe workplace. Wong et al. (2016) adopted the Human Factor Analysis Classification System (HFACS) to identify and classify the root causes of fatal fall accidents. Goh and Binte Sa’adon (2015) investigated the unsafe behavior of scaffolders based on the theory of planned behavior. They suggested that subjective norm was a key variable influencing a worker’s decision-making.
In order to facilitate safety knowledge sharing/reuse and intelligent safety management, a number of safety-related ontologies were developed. For example, in order to improve safety knowledge sharing and reuse, Le et al. (2014) developed a social network system using semantic wiki web and an ontology approach. Three main components (i.e., safety information module, safety knowledge module, and safety dissemination module) were constructed to represent construction safety knowledge based on a safety semantic wiki template. In the meantime, efforts are made to develop an ontology-based framework for job hazard analysis. For example, Wang and Boukamp (2011) developed an ontological framework which represents knowledge about activities, job steps, and hazards. The framework can be used to conduct job hazard analysis based on occupational reasoning and document evaluation mechanism. This pioneering work has demonstrated the utility and importance of ontology in intelligent safety management. They suggested that the ontological framework is integrated into BIM tools to enable more automated site safety management. In addition, in order to reduce the level of human effort in job hazard analysis, Chi et al. (2014) applied ontology-based text classification to identify hazard controls for specific unsafe scenarios. The ontology developed by them is based on three main text resources: CPWR construction solution database, the NIOSH FACE reports, and the OSHA standard. The ontological framework consists of nine concepts: task, activity, hazard, CPWR unsafe scenario, NIOSH fatality case report, safe approach, OHSA standards for the construction industry, subpart, and standard. However, the ontological framework, as well as the ontology, may not be suitable for modeling and visualizing hazard controls in BIM tools, as it appears that there are no obvious links with BIM data model (e.g., Industry Foundation Classes (IFC) data format).

Information technologies have been used to help reduce fall accidents and injuries. For example, Navon and Kolon (2006) developed an automated model that can identify dangerous work-at-height activities and areas. The schedule is integrated into the model which enables it to produce both textual and graphical reports that correspond to the schedule. The automated model was implemented in a prototype written in Visual Basic (VB), AutoCAD, and MS Project. Zhang et al. (2015) explored the automation in modeling and planning fall hazard controls based on BIM models. The tool they developed can detect unprotected slab edges and holes and install guardrail system automatically. A limitation of this study is that the fall hazard controls model is not comprehensive (limited to scaffold and guardrail systems). Other important fall hazard controls such as active fall protection systems are not included. More recently, Qi et al. (2013) developed a PTD (prevention through design) software tool to help designers implement best practices to prevent fall accidents. Using the PTD tool, automatic safety checking can be performed by using BIM technology and a knowledge base that was designed based on best practices. These efforts were aimed at reducing fall accidents by improving building design and optimizing production planning. Supported by these advancements, a part of fall hazards could be either eliminated, substituted, or managed by engineering and administrative controls. However, personal protection equipment, including AFPS, is still required as a last line of defense to protect workers in many situations (Goh and Wang 2015).

More recently, Zhang et al. (2015) developed a construction safety ontology to facilitate automated safety planning by formalizing job hazard analysis (JHA) knowledge. The ontology consists of three ontological models: construction product model, construction process model, and construction safety model. The ontology is in part based on IFC data schema and the link between the ontology and BIM is bridged. However, the ontology is aimed at job hazard analysis and does not capture high levels of detail for selection, design, and implementation of hazard control measures.

In order to better facilitate safety engineering and hazard control design in the construction industry, Guo and Goh (2017) developed a generic ontological framework which can be used as a harmonization framework for developing sub-domain ontologies. Based on the ontological framework, they developed an ontology for the design of active fall protection system (AFPS). The ontology (i.e., AFPS-Onto) provides a formal and shared knowledge base for the design of AFPS and forms an important part of the domain knowledge of FFH. Using the AFPS-Onto, Goh and Guo (2018) designed an online knowledge-based system, FPSWizard to support the design and selection of AFPS.

### 3 Research Methodology

A number of methodologies for ontology building have been developed by researchers since the early 1990s, including the Grüninger and Fox (1995) approach, the Uschold and Gruninger (1996) approach, CO4 (Euzenat 1996), METHONTOLOGY (Fernández-López et al. 1997), and SKEM (Noy and McGuinness 2001). This study adopted the METHONTOLOGY to build the FFH-Onto. The METHONTOLOGY consists of seven main steps: specification, knowledge acquisition, conceptualization, integration, implementation, evaluation, and documentation.

Specification focuses on determining the purpose, scope, level of familiarity, intended uses, and end-users of the FFH-Onto. A set of competency questions were established in this step. These questions include, but are not limited to, “What are the purposes of the ontology?”, “Who are its end-users?”, “What information should be captured in the ontology?”, and “What design criteria should be followed?”. By answering all competency questions, this step produced an “Ontology requirements specification”, which served as guidelines for the whole ontology building process.

In order to acquire knowledge for the ontology development, a number of knowledge sources were collected and studied to elicit the domain knowledge, including industry standards, Wall best practice guidelines, fall accidents, and NIOSH FACE reports (see Table 1). These knowledge sources capture structured expert knowledge and industry norms of fall protection in the construction industry.

<table>
<thead>
<tr>
<th>Corpus</th>
<th>Title</th>
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<tbody>
<tr>
<td>Industry standards</td>
<td>ANZSCE 1378 series Scaffolding</td>
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<td></td>
<td>ANZSCE 1377 Scaffolded building components</td>
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<tr>
<td></td>
<td>ANZSCE 4394 Fall protection</td>
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<td>ANZSCE 4398 Fall control</td>
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<td></td>
<td>ANZSCE 4574 Guidelines for scaffolding</td>
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<td>AS/NZS 4994 Temporary roof edge protection for housing and residential buildings</td>
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<tr>
<td></td>
<td>ANZSCE 5152 Material handling requirements for single-point anchor device for manually-based work at height</td>
</tr>
<tr>
<td>Best practice guidelines</td>
<td>ANZSCE selection, use and maintenance for fall arrest equipment</td>
</tr>
<tr>
<td></td>
<td>Preventing falls in housing construction (Safe Work Australia 2013)</td>
</tr>
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<td></td>
<td>Safe use of safety nets</td>
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<td></td>
<td>Best practice guidelines for working at height in New Zealand</td>
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<td></td>
<td>Best practice guidelines for working on roofs</td>
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<td></td>
<td>Managing the risk of falls at workplaces</td>
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<td></td>
<td>Scaffolding in New Zealand</td>
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<tr>
<td>Fall accidents</td>
<td>NIOSH FACE database</td>
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<tr>
<td>Other knowledge base</td>
<td>CPWR construction solution database</td>
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<tr>
<td></td>
<td>NIOSH FACE database</td>
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</tbody>
</table>

A comprehensive list of fall protection systems and tools were collected and categorized according to their hazard control mechanism. Key attributes of each system were extracted from
industry standards and guidelines. The main purpose of using multiple databases is to reduce or eliminate conceptual and terminological confusion and reach a shared understanding of the domain of interest.

4 FFH-Ontology

The FFH-Ontology is developed based on the generic ontological model designed by Guo and Goh (2017) (see Figure 1). The ontological model consists of three main parts: problem (i.e. specific hazards that need to be managed), context (i.e. the situation in which the problem exists), and solution (i.e. hazard controls).

The problem includes five concepts: hazard, actor, task, IFC building element, and construction method. These five concepts and their relations and attributes describe a safety problem or an unsafe scenario. Context is composed of two concepts: constraint and safety resource, which are aimed at providing information about the context in which safety problems exist and solutions are designed. The solution is composed of two concepts: hazard control measure and residual risk.

From a global perspective, the three parts are interconnected: a problem is solved by solutions which, in turn, are constrained by the context in which the problem occurs. The components (i.e., concepts and relations) of the FFH-Onto is presented as follows.

![Figure 1. The generic ontological model](image)

4.1 Concepts

Task is used to represent the hierarchy of the construction process. Being consistent to the AFPS-Onto (Guo and Goh 2017), the FFH-Onto adopted types of task defined by the Industry Foundation Classes (IFC), which consist of 12 main tasks: attendance, construction, demolition, dismantle, disposal, installation, logistic, maintenance, move, operation, removal, and renovation. Different sub-tasks (e.g., floor laying, wall framing, and installing prefabricated roof/tees) can be grouped into the 12 main tasks according to their nature. Note that this is not the only way to model task. Other ways can be referred to Wang and Boukamp (2011).

Actor defines all actors or human agents involved in hazard management. Compared to the AFPS-Onto which only defines workers and professional engineers, the FFH-Onto expands the concept by defining other key actors, including "a person conducting a business or undertaking (PCBU)", "officer", "manufacturer", "supplier", and "installer". By doing so, the FFH-Onto is able to formalize richer information and knowledge such as legal duties and manufacture information.

IFC building element comprises all elements that are primarily part of the construction of a building (BuildingSMART International Limited 2014). Considering that the FFH-Onto is in part aimed at facilitating modeling and visualization of fall hazard control in BIM models, it adopts the structure of IfcBuildingElement from IFC schema. The class IfcBuilding element include the following subclasses: IfcBeam, IfcBuildingElementProxy, IfcChimney, IfcColumn, IfcCovering, IfcCurtainWall, IfcDoor, IfcFooting, IfcMember, IfcPile, IfcPlate, IfcRailing, IfcRamp, IfcRampFlight, IfcRoof, IfcShadingDevice, IfcSlab, IfcStair, IfcStairFlight, IfcWall, and IfcWindow. By adopting the IFC building elements, the FFH-Onto is linked with BIM models and can exchange information with BIM models and other programs as an application programming interface (API).

Construction method represents the methods, techniques, and technologies that are used to construct a building. More often than not, a combination of safety work methods is required to perform safely a sub-task such as floor laying. Thus, safety knowledge of WaH can be meaningfully defined and formalized based on tasks, which facilitates the visualization of fall hazard controls in 4D schedule BIM models. When a robust knowledge base of WaH is developed, the FFH-Onto is potentially able to assist designers and engineers with integrating the concept of "design for safety" in building design. Examples of alternative construction methods include: (1) prefabricating wall frames horizontally before standing them up, (2) using precast tilt-up concrete construction instead of concrete walls constructed in situ, and (3) pre-painting fixtures/roofs before installation.

A hazard is anything in the workplace that has the potential to harm people. The FFH-Onto focuses only on fall hazard. The FFH-Onto adopts the taxonomy of constraint defined in the AFPS-Onto. The taxonomy consists of four main constraints: project constraint, design standard, regulatory constraint, and environmental constraint. Details of each constraint can be referred to (Guo and Goh 2017).

Safety resource represents resources that are consumed and designed in implementing control measures for FFH. It is composed of financial resource (e.g., money), human resource (workers, safety professionals, and project managers), physical resource (e.g., existing fall prevention and fall arrest devices and equipment), safety knowledge, and safety item (fall protection plan, best practices, and rescue plan and procedure). This component covers important information and knowledge that can justify the selection of control measures for FFH.

Control measures for fall hazards are categorized into nine main groups, including: (1) guardrail, (2) temporary work platform, (3) harness system, (4) safety mesh, (5) mechanical access plant, (6) safety net, (7) soft landing system, (8) access/egress, and (9) administrative control (see Figure 2).
According to Safe Work Australia (2016), control measures for FFH can also be categorized into a 5-level hierarchy. Level 1 controls aim to eliminate the risk of a fall by either carrying out tasks on the ground or platforms (e.g., flat roof) with edge protection (e.g., parapet). Level 2 controls represent fall prevention devices and equipment, such as temporary work platforms (e.g., scaffold, elevating work platforms, mast climbing work platforms, and ladders), guardrails, and safety mesh. Level 3 controls include any work positioning systems that can restrain workers within safe areas. Level 4 controls are used to arrest a fall when it is not reasonably practicable to prevent a fall. For example, catch platforms, and active fall arrest systems are common measures to arrest a fall. Safety nets should be used when it is not practicable to provide scaffolds or temporary guard railing. Level 5 captures all administrative controls such as safety training.

Residual risk refers to hazards and risks remaining after the inherent risks have been reduced by hazard controls. Any implementation of specific hazard controls may bring about new risks or leave some risks unaddressed. For example, the design of active fall arrest system may leave some residual risk such as poor installation, inadequate training and supervision.

4.2 Semantic relations

Semantic relations are defined as “meaningful associations between two or more concepts, entities or sets of entities” (Kho and Na 2006). Semantics refers to the meaning of the concepts within an ontology. Semantics play important roles in information modelling and knowledge representation. There are five main semantic relations: (1) Hyperonym-hyponym relations: they refer to the relations between a broader and narrower concept; (2) Meronym-Holonym relations: they refer to the relations between a concept and its constituent parts; (3) Concept-object relations: they refer to a class and its instances; (4) Cause-effect relations: they refer to cause-effect relations between concepts using causative verbs; (5) Locative/spatial relations: they are used to specify how a concept is located in space in relation to other concepts. Examples of semantic relations are provided in Table 2.

4.3 Attributes

According to El-Gohary and El-Diraby (2010), an “attribute” is defined as “a characteristic that describes a thing”. Modelling and visualizing fall hazard controls without information about attributes is less meaningful and useful. Attributes should cover information that is important to end-users of an ontology. For example, it is not enough to model and visualize a safety net without any information about its size, material, class, energy absorption capacity.

The information is significant for selection and implementation of safety nets on site. Note that attributes of the concepts of active fall protection system are not presented here. Details can be referred to (Gao and Goh 2017). “Hazard control mechanism” is an attribute of hazard control measure and it is inherited by all sub-classes of hazard control measure. The attribute has three values: elimination, isolation, and minimization, which are consistent with the traditional hazard control hierarchy. Key attributes of other main concepts are presented in Table 3.
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hazard controls.

4.4 Coding

The FFH-Onto was coded using Protégé 5.2.0, as shown in Figure 3. Protégé is a free, open-source ontology editor and framework for building intelligent systems (Horridge et al. 2004). In protégé, “Classes”, “Object properties”, and “Data properties” are used to model concept, relations, and attributes, respectively.

Figure 3. Screenshot of the ontology editor Protégé.

5 Conclusion and Further Research

This paper developed a lightweight ontology for the domain of fall from height in the construction industry. It represents an effort to develop the global ontology for construction safety hazard management (CSHM-Onto).

The FFH-Onto builds itself on a generic ontological framework. A major consideration is that a hierarchy of hazard control measure ontologies (FFH-Onto, AFPS-Onto, and struck-by-objects ontology) can be built and combined based on the harmonization framework. The lightweight ontology captures the vocabulary (i.e., concepts, attributes of and relations between the concepts) in the domain of fall from height in the construction industry. In particular, nine groups of fall hazard controls were categorized, including (1) guardrail, (2) temporary work platform, (3) harness system, (4) safety mesh, (5) mechanical access plant, (6) safety net, (7) soft landing system, (8) access/egress, and (9) administrative control.

Compared to previous safety-ontologies developed for job hazard analysis, the FFH-Onto is more comprehensive, powerful, and flexible. It serves purposes beyond conducting job hazard analysis. By unifying multiple databases in the FFH domain, it can be used to (1) promote knowledge reuse and sharing, (2) facilitate the development of knowledge-based systems, and (3) improve the modeling and visualization of fall hazard controls in BIM tools.

The ontology can be used to facilitate knowledge re-use and sharing among the end-users (e.g., designer, engineer, safety professional, supervisor, and site manager. As a foundation of knowledge engineering, ontologies represent an effort to engineer domain knowledge into a high level of human expertise.

The FFH-Onto formalizes empirical experience, standards, best practices in the domain of fall from height in the construction industry. Specific fall protection systems and devices are explicitly defined and thus it promotes modeling and visualization of fall protection in BIM models. Engineers and safety practitioners can demonstrate the design and installation of hazard controls (e.g., active fall protection system and guardrail systems) in BIM models and therefore improve communication and safety planning.

Recent years have seen a growing interest in developing knowledge-based systems for construction safety engineering and management. Building these intelligent systems poses special requirements for interoperability. Thus, establishing agreements about domain knowledge becomes critical. The FFH-Onto captures consensual the domain knowledge in a generic way and as such facilitates interoperability of formal knowledge across computer programs. By organizing objects (e.g., workers and scaffold) into categories, semantic networks, rules, and logic can be designed and integrated into computer programs for certain tasks. For example, by capturing a working at height scenario using concepts like actor, task, building element and their relations and attributes, it is possible to write rules that enable automatic hazard recognition and classification based on additional information extracted from BIM models. Intelligent hazard control recommendation systems could also be designed based on the temporal-spatial relationships between building objects, materials, tools, process, practices, and workers.

The ontology developed in this paper has the following limitations. First, the proposed lightweight ontology needs to be further developed by including axioms and constraints. Second, FFH-Onto is by no means a “perfect and only” ontology to represent the knowledge of FFH domain. Other representation strategies are possible. Future efforts should be made to develop ontologies for other key hazards such as struck by objects. Once local ontologies are developed, they can be mapped and integrated into a global ontology of construction safety hazard management. The success of these efforts would significantly promote automation in construction safety engineering and management.
Investigating Quantity Surveying Entrepreneurship: The Case of Sri Lanka

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Abstract:
The Quantity Surveying (QS) profession is under pressure and QS entrepreneurship is an area in need of further research. No explicit body of knowledge, however, has been devoted to the context of Sri Lanka. The present study aims to address this issue through exploring the key aspects of QS entrepreneurship in Sri Lanka. A review of the literature was conducted, followed by a mixed approach. Six interviews were carried with industry experts using a questionnaire survey to elicit perceptions from QS. Findings provide: (1) a picture of the current QS entrepreneurship in Sri Lanka, (2) problems and issues affecting it and (3) several remedial solutions to deal with the identified problems. According to the findings, the most serious problem with current Sri Lankan QS entrepreneurship is the lack of competency and an absence of IT-based and automated solutions in providing service, which make the market limited and risky in long term outlook. The study contributes to the field by unearthing the QS entrepreneurship environment in Sri Lanka, carrying implications for QS professionals, as well as policy makers.

Keywords:
Entrepreneurship, Market problems and issues, Professional Development, Quantity Surveyor, Sri Lanka.

1 Introduction

Entrepreneurship is defined as the “discovery of opportunities and the subsequent creation of new economic activity, often via the creation of new organisation” (Veciana, 2007). An active entrepreneurship sector is a major contributor to the future development of any economy, whether they are rich or poor countries. By the same token, skills in commerce, entrepreneurship and management have become increasingly important for the Quantity Surveying (QS) profession (Oke et al., 2017). QS is seen as an important profession on construction projects, known as a cost expert that manages a wide range of tasks associated with project cost for the client. This predominantly entails quantification, preparing bills of quantities, estimation and eventually pricing. The wide variety of skills possessed and the know-how to apply them in different scenarios render a QS professional ideal to pursue entrepreneurial avenues. A QS professional has a broad range of expertise, including technical, professional, managerial, financial, and legal, hence it is opportune to discuss the concept of entrepreneurship in the context of QS (Oke et al., 2017).

At present, however, the traditional role of QS has perished and been superseded by a number of diversified roles which require a higher level of knowledge and skill to perform (Ofori and Toor, 2012). The prime reason for this transition is technological advancement (Smith, 2011). This has rendered some of the core QS services obsolete (Aibinu and Venkatesh, 2014). The upside nonetheless is that this has allowed the QS to play a more dominant role in construction projects. That is because, the modern QS professional provides input to a project regarding a wide range of aspects, including project management, contract administration and dispute resolution. This transition the profession is undergoing has opened new doors for QS professionals in many areas; one of which is entrepreneurship.

With this in mind, the number of institutes providing QS courses is steadily mounting across the globe. This clearly poses a threat to conventional QS, since more supply would ultimately culminate in lower wage rates. In long-term outlook, the typical QS professionals may find it challenging to secure employment (Olanipekun et al., 2014). Therefore, it is opportune to contemplate alternative career paths, including entrepreneurship, and this warrant further research into QS entrepreneurship. Despite this, research into QS entrepreneurship has been very minimal. There is a clear deficiency in entrepreneurship research and education, particularly in the context of developing countries (Nabi and Liñán, 2011). This study is an attempt to address the above gap in the body of knowledge, as well addressing the problems facing QS graduates.

The aim is to identify the key aspects related to QS entrepreneurship and provide a picture of the QS entrepreneurship in Sri Lanka. The study findings would be used to establish guidelines and best practices to inform QS entrepreneurship practices and assist academics in designing better curricula for QS education.

2 Background

“An quantity surveyor is a professional who attempts to ensure the resources of the construction industry are utilised to the best advantage by providing the financial management and consultancy service to the client during the construction process” (Davis et al., 2007). In this context, QS firms are service-based companies that manage finance-oriented issues for clients, drawing upon infrastructure cost and value management expertise (Olanipekun et al., 2014). QS firms typically possess mechanistic characteristics, where jobs are adequately narrowed in scope, allowing employees to become experts in specialised functions with high role clarity so that standard performance can be achieved (Owusu-Manu et al., 2014). One common attribute associated with all QS firms is their heavy dependency on skills, expertise, and knowledge of their employees to address clients’ needs (Aibinu and Venkatesh, 2014, Olanipekun et al., 2014). The success of QS firms hinges largely on their staff members (Abdul-Rahman et al., 2011). As a result, QS organisations are becoming more and more concerned with educational qualifications of their employees, to protect their clients from substandard QS practices (Oke et al., 2017). QS firms should strive to keep abreast of the latest developments in the market, to survive in a dynamic construction environment (Aibinu and Venkatesh, 2014). Particularly, due to the emergence of Building Information modelling in the construction market, QS firms are facing threats to their traditional methods (Aibinu and Venkatesh, 2014). The changing client needs have also exposed QS firms to new challenges, reiterating the importance of information and communications technology to enhance the profession of a QS (Dada et al., 2016). Moreover, QS firms are increasingly under pressure, given the prospect of automated, BIM-based quantity take-off and estimation.
In general, due to the wide range of challenges facing the traditional nature of QS profession and firms, new scenarios are to be adopted and new directions are to be discerned, in order to survive in the market (Davis et al., 2007). A remedial solution for the QS profession is defining and getting involved in new markets, or penetration into existing markets (Frei et al., 2013), as discussed below.

3 QS Profession and the Potential Entrepreneurial Avenues

As one remedial solution to deal with the challenges as discussed, QS firms are now providing a wide range of services, including taxation advice, insurance valuations etc. among others (Abidin et al., 2010). The increased reliance on digital means of collecting and processing data has made the QS role, capable of entering into various areas of analysing and interpreting project information (Owusu-Manu et al., 2014). Furthermore, a greater focus on sustainability has opened new avenues for QS professionals with regard to environmental impact assessment, particularly quantification of the environmental impact of various construction activities. Alternative dispute resolution and expert witness services too have great future potential where QS firms are considered (Frei et al., 2013). QS professionals are increasingly engaging in various features of facility management (Ho, 2013). They also provide various services to the oil and gas industries and rail networks (Owusu-Manu et al., 2014). Furthermore, Ho (2013) predict that the QS professionals are likely to be involved in specialist services such as project monitoring, development appraisal, management, and disaster management.

With the above in mind, there is no shortage of research studies that acknowledge the great potential of QS profession to engage with entrepreneurial avenues and entrepreneurship activities (Owusu-Manu et al., 2014).

4 Research Methods

The primary method for conducting the present study followed a qual → QUAN sequence as a category of mixed methods research. Due to the novelty of the topic in the context of the study (Sri Lanka) and a lack of prior investigation, conducting a qualitative approach as the first phase of a mixed methods research was deemed essential, as recommended by Amaratunga et al. (2002). A common method for qualitative studies in construction research is conducting interviews (Amaratunga et al., 2002), as described next. Interviews with six experts (hereafter mentioned as A, B, C, D, E and F) were conducted. These interviews assisted in identifying different types of QS firms prevailing in Sri Lanka and developing the criteria to evaluate different types of QS. A detailed account of the interviewees is provided in Table 1.

The outcomes were analysed using NVivo 11 package based on the number of respondents who supported each claim and the number of references made with regard to each of those and were aggregated with the outcome of the literature review to construct the questionnaire of the study. Subsequently, a questionnaire survey was carried out involving two types of questionnaires (Types A and B). The 52 completed Type A questionnaires were used to rank the characteristics of QS enterprises and the perspective of QS entrepreneurs/executives. On the other hand, 44 completed Type B questionnaires were used to provide information on the entrepreneurial avenues for Sri Lankan QS professionals. The questionnaire survey was conducted with the use of QS entrepreneurs, executives and general practitioners who have more than 10 years experience in the Construction Industry.

The mean and standard deviations of an individual factor alone are not adequate to obtain its overall ranking as they do not reflect the relationship between them. Therefore, RII was used to rank the characteristics of QS enterprises and the perspective of QS entrepreneurs/executives from the literature and semi-structured interviews, based on their importance. RII helps to find the contribution a particular variable makes to the prediction of a criterion that can vary both by itself and in combination with other predictor variables. Past researchers too have used RII calculated using the equation given below, to identify the importance of factors as perceived by groups of respondents.

A rating scale of 1 to 5 was adopted with 1 representing the lowest level of effect and 5 representing the highest level. The RII was evaluated by the following expression:

$$RII = \frac{\sum w}{A \times N}$$

where RII= Relative Importance Index; w= Weighting given to each factor by the respondents; A= Highest weight and N= Total number of respondents.

5 Findings of the Study

Findings section discusses (1) a picture of the current QS entrepreneurship in Sri Lanka, (2) problems and issues affecting it and (3) several remedial solutions to deal with the identified problems.

2.1 QS Enterprises in Sri Lanka

The interviewees were in agreement that QS enterprises fall within three categories: Consultancy, Construction, and Firms which undertake only overseas projects. Table 2 illustrates the general characteristics of QS firms found in literature and approved by the
Interviewees. The questionnaire survey was used as a tool to differentiate among the three categories of QS enterprises based on the characteristics as illustrated in Table 2. This was through demonstrating the level of emphasis on each characteristic according to the ranking values for each item for each category of enterprise.

The findings present novel insights. First, whereas the IT capacity is well-received by consultancy enterprises, construction enterprises do not see IT as a key success factor. This premise was corroborated by the statement of interviewees, where none of respondents from the construction category referred to IT as a key enabler for their businesses.

“...we are not that much into IT. Our strength lies in marketing and sales. The employees do wonders with Excel and that meets our expectations with regard to IT...” (Respondent D).

Second, it came to light that the turnover generated by an average consultancy firm would be around 10% of the turnover generated by their contracting counterparts. This results in QS consultancies lack the resources to adequately invest in IT. This showed a serious problem with the state of IT application among Sri Lankan QS enterprises.

Another interesting finding was the dominance of deviation from standard practices culture among consultants, compared against their construction counterparts, as illustrated in Table 2. Deviating from standard practices such as standard methods of measurement or standard conditions of contract is quite common.

“...we have to deviate from standard practices. Standards developed for well-developed industries are not appropriate for our industry. If there were standards specifically developed for the Sri Lankan context, we would adhere to those...” (Respondent B).

Enterprises which carry out overseas projects have jobs with a much narrower scope compared to the other two types of QS enterprises. Due to narrow scope and repetitive work, the employees become specialised in their roles. All 3 types of organisations are small in nature with generally less than 20 employees. Moreover, construction companies owned by QS professionals are much smaller than other reputed construction companies in the island. Firms which undertake foreign projects however are usually larger than general cost consultancies, hence have a better potential for growth. As shown in Table 2 and based on the consensus among the interviewees, QS enterprises in Sri Lanka face considerable fluctuations in demand. The same is applicable for firms that provide services to foreign projects because the demand for their services is hugely dependent upon the market conditions in the Middle East, their main market overseas.

2.2 Business evaluation for QS enterprises

Owners and executives of QS enterprises participating in the survey were required to assign scores with respect to the ten criteria, as illustrated in Table 3, to provide a picture of the market and the business health of existing QS enterprises.

| Table 3: Market and the business health evaluation of existing QS enterprises |
|----------------------|----------------------|----------------------|----------------------|
| Criterion | Consultancy (Storm) | Construction (Foreign Projects) | Consultancy (Foreign Projects) |
| | RII | Rank | RII | Rank | RII | Rank |
| The financial return generated by the company is satisfactory | 0.644 | 5 | 0.800 | 2 | 0.775 | 1 |
| Work-life balance can be achieved with the amount of work being managed | 0.722 | 3 | 0.600 | 7 | 0.750 | 3 |
| The work being undertaken provides job satisfaction | 0.856 | 1 | 0.867 | 1 | 0.750 | 3 |
| This business enterprise has a high risk of failure | 0.589 | 6 | 0.567 | 8 | 0.775 | 1 |
| The enterprise enables its owners to discharge their social responsibilities | 0.659 | 4 | 0.767 | 5 | 0.675 | 7 |
| The business enterprise may be used as a means of enhancing the public image and recognition of its owners | 0.733 | 2 | 0.767 | 5 | 0.700 | 6 |
| The organization faces fierce competition from its rivals | 0.544 | 9 | 0.800 | 2 | 0.750 | 3 |
| This type of organization requires a substantial amount of initial capital | 0.556 | 8 | 0.800 | 2 | 0.625 | 8 |
| Government regulations are conducive to the operations conducted by the organizations | 0.567 | 7 | 0.567 | 8 | 0.425 | 10 |
| The owners of the organization may be able to cease operations and contemplate a different career option without severe encumbrances (ease of exiting) | 0.522 | 10 | 0.500 | 10 | 0.450 | 9 |

The findings in Table 3 indicate that QS consultancies typically yield a less satisfactory return compared to construction firms and firms which provide consultancy for overseas projects. In line with this view, respondents from consultancies agreed that they can earn a much higher income as a general QS practitioner or in consultancy with foreign projects, where higher prices can be charged. Another important point to note is that these firms usually get paid in US dollars and since the Sri Lankan rupee has been constantly depreciating, their income has been on the rise when converted to rupees for the past few years. Companies that only undertake foreign projects are, however, facing a higher risk of failure, as argued by the respondents.

“...our foreign projects division obviously is at a greater risk of failure since the amount of work we get is directly influenced by the market conditions in other countries. In fact, when the oil prices plummeted, there was a significant reduction in the number of jobs...” (Foreign Projects).
we got…” (Respondent C).

As another finding that came to light concerned the different of the amount of investment required by different types of QS enterprises (see Table 3). Compared against construction type enterprises, both cost consultancies and those that undertake foreign projects require a minuscule amount of capital to commence business, a point verified by the statement of interviewees.

“…this type of a firm may not require a substantial amount of initial capital to start with. What may be a big challenge is that we have a foreign branch in Qatar which helps us to effectively connect with our foreign clientele. This however, entails a significant investment...” (Respondent B).

2.3 Entrepreneurial Avenues for a Sri Lankan QS Professional

Table 4 depicts potential entrepreneurial avenues available for a Sri Lankan QS professionals based on ranking the options extracted from the literature and suggested by the interviewees (all included in Table 4).

<table>
<thead>
<tr>
<th>Avenues</th>
<th>RI</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project management</td>
<td>0.825</td>
<td>1</td>
</tr>
<tr>
<td>Consultancy services to contractors</td>
<td>0.819</td>
<td>2</td>
</tr>
<tr>
<td>Technical auditing</td>
<td>0.813</td>
<td>3</td>
</tr>
<tr>
<td>Construction</td>
<td>0.806</td>
<td>4</td>
</tr>
<tr>
<td>Alternative Dispute Resolution</td>
<td>0.800</td>
<td>5</td>
</tr>
<tr>
<td>Expert witness</td>
<td>0.800</td>
<td>5</td>
</tr>
<tr>
<td>Management consultants in the construction industry</td>
<td>0.788</td>
<td>7</td>
</tr>
<tr>
<td>BIM modelling and management</td>
<td>0.775</td>
<td>8</td>
</tr>
<tr>
<td>Public Private Partnerships &amp; Private Finance Initiative</td>
<td>0.694</td>
<td>9</td>
</tr>
<tr>
<td>Insurance advise</td>
<td>0.650</td>
<td>10</td>
</tr>
<tr>
<td>Facilities management</td>
<td>0.625</td>
<td>11</td>
</tr>
<tr>
<td>Taxation advice</td>
<td>0.581</td>
<td>12</td>
</tr>
<tr>
<td>Land reclamation and waste management</td>
<td>0.563</td>
<td>13</td>
</tr>
<tr>
<td>Environmental Impact Assessment</td>
<td>0.531</td>
<td>14</td>
</tr>
</tbody>
</table>

The illustrated in Table 4, project management, consultancy services to contractors, technical auditing, expert witness, construction, alternative dispute resolution and expert witness are the available entrepreneurial opportunities with a high potential for QS professionals. On the other hand, environmental impact assessment, land reclamation and waste management, taxation advice, facilities management and insurance advice are the opportunities with less potential.

“…options such as taxation advice, insurance advice, ELA and land reclamation and waste management have been talked about for decades as potential areas that a QS may enter. But hardly any QSs have diversified into those areas. Hence, I personally don’t believe that those options denote that much future potential...” (Respondent A).

Many respondents were zealous about BIM, PPP and PFI and the concept of management consultants in the construction industry, due to the unpredictable financial viability of those options in Sri Lanka. All the respondents however, remarked that the aforementioned concepts are being practiced in developed countries and that the local industry is far behind. Few of the respondents further stated that in the Sri Lankan industry, there is a shortage of professionals specialized in areas such as value management and life-cycle costing.

“…private public partnerships are within the QS’s scope as for as the technical aspects are concerned. But when it comes to a third world country like Sri Lanka, I have my doubts on its practical viability due to the significant amount of politics and corruption involved...” (Respondent B).

6 Discussion of the Findings

The QS profession is undergoing a dramatic change around the globe, and the picture of QS market, provided by the present study, provides valuable insights into what developments are needed within the Sri Lankan context.

The first pathway to follow for QS professionals in Sri Lanka and policy makers is promoting the integration of IT into their businesses. In essence, lack of attention to the necessity of this evolution might result in Sri Lankan QS professionals and enterprises losing their competitiveness in foreign markets and become irrelevant to the contemporary construction industry in long-term. That is because, with the emergence of BIM in the market, there is great potential for clients and contractors to receive accurate, specified estimations in electronic and imperable format (Oraee et al., 2017).

Moreover, the avenues with great potential for QS professionals in Sri Lanka were mostly related to areas revolving around project procurement and financial management, skills to analyse the economies of construction along with knowledge of contract practice and measurement, similar to the case observed by Nkado and Meyer (2001) in South Africa. Focus in developing these competencies is important in terms of the capability of QS enterprises to remain competitive in foreign markets where skills necessary are narrowed towards the particular skills and abilities expected of QS professionals.

As the result, the message here is that policy makers and QS professionals have to devise plans to make sure that QS graduates and professionals poses the core competencies and skills of the profession and continue to develop this expertise. Particular attention should be on IT, because technological advances, particularly BIM continue to automate QS activities, asking for practitioners to have the capabilities and skills to run these tools.

The findings also reveal the high rate of risks, fluctuations in demand in the market and the necessity of large amount of investment, as issues affecting entrepreneurship environment for Sri Lankan QS enterprises. Besides, the findings revealed a wide range of areas in which QS professionals and enterprises might have opportunities for providing service. Covering almost all sectors of the built environment, creates great potentials for QS enterprises to take advantage of partnering arrangements, in order to overcome the challenges facing them in the market, as discussed (Olatunji et al., 2017). This premise calls for enhancing collaboration and allocation of specific resources among QS enterprises and among QS enterprises with other specialised service providers in the construction sector.
7 Conclusions

The study provides a picture of the Sri Lankan market for QS professionals and enterprises. Despite the availability of similar studies in the literature, the present study is the first from Sri Lanka that identifies the issues with the current market for professionals and enterprises and suggest several remedial solutions to tackle with the identified problems.

Despite the novelty, the findings of the study are to be seen in light of several limitations. First, the sample size of the study is relatively small, hence further research into the topic using larger samples is warranted. Moreover, the main focus was on economic and financial features of the market. Future research studies are to target human resource related features and areas associated with turnover of staff and satisfaction of personnel in QS enterprises. Besides, the remedial solutions provided are not validated within the Sri Lankan context. This provides a fertile ground for future investigations, to test the validity of suggested solutions for Sri Lanka.

8 References


Prototype SafeSim – a virtual game for construction safety education
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Abstract:
Construction sites remain as one of the most hazardous workplaces in Singapore. According to the Ministry of Manpower, the construction sector was the top contributor of fatal and major injuries among all sectors. Despite the importance of Workplace Safety and Health (WSH), there is still a lack of emphasis on WSH in construction-related tertiary education. The first author teaches an elective final year module PF4202 “Safety, health and environmental (SHE) management”, in the Project and Facilities management (PFM) degree programme in the National University of Singapore (NUS). One of the difficulties in teaching construction SHE risk management at tertiary level is that students lack the practical on-site experience to comprehend real-world processes and challenges in on-site risk management. Limited time and resources at the educator’s disposal have further exacerbated the difficulties. Thus, a prototype game called SafeSim was developed in 2017 as a simulation-based authentic learning alternative to real on-site experience in WSH. Students immerse themselves in a simulated site and conduct a site inspection for hazards and good practices within a time limit. At the end of the session, the students will receive immediate feedback for their submission followed by a debrief on their performance by the educator. Industry practitioners have been consulted for their valuable input to ensure SafeSim provides an accurate representation of a site. Positive feedback has been gathered from both practitioners and students during the game trials. This paper will describe the overview of the prototype SafeSim game and future arrangements.

Keywords:
Authentic learning, Construction safety, Hazard identification, Simulation game, Workplace safety and health

1 Introduction
Fatalities in the construction industry are much higher compared to other industries which signifies the workplace safety and health (WSH) risk to construction workers. In the U.K., the annual average number of fatalities over five years is 39 (Health and Safety Executive, 2017). Construction and extraction occupations in the United States contributed 48% to the total fatal injuries sustained by workers (U.S. Bureau of Labor Statistics, 2017). In Australia, the construction industry remains as one of the top contributors to overall workplace fatalities; 35 out of 182 workplace fatalities came from the construction industry in 2016 (Safe Work Australia, 2017). Even though Singapore’s workplace fatal injury rate in the construction sector has decreased from 4.9 per 100 000 employed persons in 2016 to 2.6 per 100 000 employed persons in 2017, the industry significantly contributed 29% of total workplace fatalities and injuries (Ministry of Manpower, 2018). Workplace injuries and fatalities not only cause pain and suffering to the individual involved but also translates to exorbitant costs to the country. An estimate of 3.9% of the global Gross Domestic Product (GDP) is incurred as a result of workplace injuries and fatalities. (Elsler, Takala, & Remes, 2017) In Singapore, cost of work-related injuries and fatalities is estimated to be 3.2% of the country’s 2011 GDP. (Loke et al., 2013)

Despite the importance of WSH, there is a lack of focus on WSH education at the tertiary level (Pedro, Le, & Park, 2016). Furthermore, due to the practical nature of WSH issues, it is essential for students to understand hazards and WSH management challenges in their real-world settings. An effective WSH education would facilitate better WSH management (Tooke, 2005). However, it is difficult to provide an authentic learning environment for students to understand the challenges of hazard identification and control. The first author faces these challenges when teaching an undergraduate elective WSH module in the Project and Facilities Management programme in the Department of Building, National University of Singapore. Some of these barriers include the lack of industry partners who are willing to provide access for each cohort of about 80 to 90 students, concerns about students’ safety during the visits, the disruption to normal operations during visits leading to a lack of authenticity, limited exposure time during the visits and, the lack of resources to support the visits.

To make up for the absence of practical experience, this paper introduces SafeSim, a prototype computer simulation game, created based on principles of authentic learning to improve WSH education in the first author’s undergraduate module. SafeSim aims to provide students with an authentic virtual environment to exercise and reinforce their learning pertaining to WSH. From hazard identification to recognising good practices, students are given an opportunity to explore the virtual construction site safely and are assessed on their performance during the game. The game provides prompt feedback for effective learning conducted in a safe environment.

This paper presents the prototype SafeSim as a qualitative case study of how a simulation game is designed to implement the pedagogical concept of authentic learning to improve WSH education in a tertiary institution.

2 Literature Review

2.1 Construction Safety and Health Training Education
Education in construction safety and health has been highlighted to be important in accident prevention in the long-term. Educating students on safety literacy equips them with safety competencies that can contribute to long-term effective management in accident prevention (Saleh & Pendley, 2012). Unfortunately, safety education has been confined within classrooms and restricted to learning via theory due to challenges in arranging for site visits accommodating a whole cohort of students and time constraints as experienced by the first author. On-site experiences are valuable and are irreplaceable by theoretical knowledge yet they are often characterised as high risk (Pedro et al., 2016). Thus, the advent of educational institutions utilising technology to provide an authentic environment for collaborative learning in the form of games (Le, Pedro, & Park, 2015).

Lin, Son and Rojas (2011) conducted a pilot study to explore the opportunities and limitations of 3D video game technology in the course of construction safety education.
The pilot study showed that students had an engaging and motivating learning experience. Students play the role of a safety inspector and have the responsibility to point out all on-site hazards in-game. After the game, they conducted a survey for the students on realistic gameplay and motivation among other factors. In their conclusion, the authors recognized that the game is only a beta and its realism need to be improved as well as to change the game application from “hazard identification” to “positive site safety improvement” by introducing more pedagogical design consideration.

Li, Chan, and Skitmore (2012) developed Virtual Safety Assessment system (VSAS) where users could experience a realistic virtual environment with unsafe site conditions, unsafe working behaviours and unsafe construction methods or sequencing. They used post-interviews after the game trial where the results indicate that the VSAS helped pinpoint the weaknesses of users (construction workers) who have already passed the traditional assessment process. Data also showed that users who have not had any prior training performed particularly poor with VSAS. In the conclusion of their study, the study showed that the game is a more effective means of assessment than the traditional method.

2.2 Simulation Game

Cruickshank and Telfer (1980) defined a simulation game as one “…in which participants method. study showed that the game is a more effective means of assessment than the traditional training performed particularly poor with VSAS. In the conclusion of their study, the study showed that the game is a more effective means of assessment than the traditional method.

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Prior to each session of gameplay, the educator will familiarise students with the game. After which, each team will select a team leader who would launch a game for other to join the game. The game has a time limit of 60 minutes, with 45 minutes for spotting hazards and good practices and 15 minutes to sort their photographs and prepare for group submission. The game has an in-game channel for team communication. Nearing the 45-minute mark, an automated message would remind the players of their remaining time to complete their gameplay tasks as they move on to the photo submission page for the last 15 minutes. At the photo submission page, team members would gather around the team leader’s screen and help sort the photos. Participants can check their answers against a model answer script which has a complete list of all the hazards and good practices modelled into the game.

In this paper, the gameplay will be discussed in detail to provide as a reference case study for other educators intending to implement authentic learning through a computer simulation game. An overview of the game can be found in this YouTube video: https://www.youtube.com/watch?v=o3-E_f_w_a_w.

4 Case Study: SafeSim Gameplay

This section discusses the SafeSim gameplay in detail.

4.1 Briefing and Grouping

Upon logging in SafeSim, the player can either create a game or join an existing team to commence the game session. New players can access the tutorial to familiarise themselves with the game controls and shortcuts prior to starting a game. The tutorial as seen in Figure 2 is also accessible in game via the [F1] shortcut in-game. Players can move in the respective four directions using keyboard keys [W], [S], [A] and [D] - forward, backwards, left and right. To simulate an authentic experience in movement, players can hold the [Shift] key to run or [Ctrl] key to crouch to speed up movement or see from a different perspective. Accompanying the movement controls are tools which the players can utilise to facilitate their site investigation. Using the [E] when near items such as boards and tags allow players to view them in closer details. Tools such as the camera, measuring tool, phone, album, map will be further elaborated in the next section.

4.2 Tools

Tools are useful functions players can access within the game to facilitate navigation and identification of hazards and good practices.

4.2.1 Camera

As in the real world, the camera is a tool (see Figure 3) to allow site personnel to capture photographs of hazards and good practices. These photographs will be used later for submission. The camera tool can be accessed by [1] shortcut; as indicated at the bottom right of the screen. Upon capturing an image, players would have to classify the photograph into either hazards or good practices. Re-classification is possible at a later stage. Also, the subject of the photograph must be outlined in red for the system to assess the player’s submission.

4.2.2 Measurement

The measuring tool (see Figure 4) provides players the ability to measure the distance between two points and assess players’ theoretical knowledge and ability to identify hazards. This allow players to assess for potential safety breaches such as safety barriers failing to meet the standard height requirement hence it poses as a hazard of fall from height. Other uses of measurement can include ensuring the distance between the mid rail and top rail should not be more than 600m and emergency walkways are of adequate length.
4.2.3 Phone

The phone is a useful tool allowing players to contact the office to verify either the work permit and workplace safety, health and environment (WSHE) and if the worker’s permit to work is valid. Figure 5 provides an example of a dialogue with the office operator. The information required can be gathered from interacting with non-player characters (NPCs). With the information collected, players can key in the information via the phone function to find out if a worker’s certification is valid to carry out specified tasks such as lifting and excavating. The conversation and language are designed to be aligned with on-site linguistic norms.

```
Office: Hi what do you want to know about?
Player: [Verify work permit and WSHE training]
Office: Ok what permit do you want to know? (Select one of the following)
Player: [Lifting] [Excavation] [Scaffolding]
Office: Please tell me the PTW number.
Possible outcomes: This worker has/has not attended the WSHE induction course.
```

Figure 5: Phone conversation dialogue

4.2.4 Map and movement

The map is a useful tool allowing players to check their current location and provide an option for players to teleport to other locations indicated by a red dot. NPCs are represented by a yellow dot while a player is represented by a white dot. Moving around the map can be done by scrolling to zoom in and out for a better view of the site. Players can utilise the map via the [M] key to coordinate areas to cover as a group due to the time limit. Tasks can be allocated to individuals using the map to coordinate the areas each player is responsible for as part of authentic learning through role-play.

There is also an in-game channel for players to communicate via the [Enter] key. Players can chat and update each other on their locations in-game as indicated by a red dot. Players can utilise the map via the [M] key to coordinate areas to cover as a group due to the time limit. Tasks can be allocated to individuals using the map to coordinate the areas each player is responsible for as part of authentic learning through role-play.

There is also an in-game channel for players to communicate via the [Enter] key. Players can chat and update each other on their locations in-game as indicated by a red dot. Players can utilise the map via the [M] key to coordinate areas to cover as a group due to the time limit. Tasks can be allocated to individuals using the map to coordinate the areas each player is responsible for as part of authentic learning through role-play.

Also, the player can choose to [Select] or [Unselect All] photographs for submission instead of selecting each photograph individually as seen in Figure 5 before confirming for submission. Prior to submission, players would discuss in their groups to articulate and reflect on their choices of photographs as part of the authentic learning experience. With the opportunity to collaborate to reflect real-life context of risk management, players can provide different perspectives based on the roles they played in SafeSim.

4.3 Interaction with non-player characters (NPCs)

In the virtual environment, players can interact with NPCs by approaching until a prompt “Click to talk” appears. Either pressing the hotkey [E] or clicking on the NPC would initiate a conversation. Players can learn more about the NPCs through interactions such as asking them about the work they are engaged in and request for their work pass numbers. These work pass numbers are useful for verification purposes via the phone tool. Figure 6 shows a conversation dialogue and the possible actions to take during an interaction with a NPC. Industry practitioners have been consulted to provide a realistic conversation set in the local context.

```
Player: Uncle, do you have the daily checklist?
NPC: 有有有，在里边。(Yes, I do. It's inside.)
Player: OK ok. This is good. Carry on.
```

Figure 6: Conversation dialogue with NPC

4.4 Submission

Before time runs out, players can use [F6] to jump to the selection of photographs for submission seen in Figure 6. Prior to submission, players can access photographs taken via [Tab] key at any time. It is up to the player to re-categorise the photographs taken so far or delete unwanted photographs by dragging it to the trash bin. Additionally, by clicking on individual photographs, the player is free to include any notes or explanation in the space below the photograph seen in Figure 7. Doing so would facilitate the selection of photographs for submission during group discussion due to a limited number of photographs that could be submitted.

```
Office: Do you know what this means?
Player: No, I do not. It's inside.
Office: Please tell me the PTW number.
Choose one of the following:
[Take a photo of NPC and document]
[Do nothing] [Give me your ID]
```

Figure 7: Access to photograph album (left); Function to input text on individual photograph (right)
4.5 Feedback and debrief
After submission, players can view their scores and are given an option to review their answers against model answers to simulate authentic assessment with access to expert performance. With reference to Figure 9, review allows players to view all hazards and good practices in SafeSim which are matched with the player’s correct answers. Thus, players can understand the hazards and good practices that were identified correctly and incorrectly against the ones that were missed out.

In the event a player is keen to find out why the subject captured in the photograph constitutes as a hazard or good practice, double-clicking the photograph enlarges the photograph which comes with a label to justify why so. For instance, Figure 9 showed staircase LED which exemplifies it as a good practice as it highlights the location of the staircase as an emergency escape route in a dark area to guide workers to. Learning would be reinforced as the answer is provided in the most authentic context on top of theoretical knowledge.

5 Conclusion and Further Research
The prototype SafeSim game was implemented in October/November 2017. From the surveys done after the game trials, the feedback for the game was good. The trials included practitioners to bring in a different set of perspectives. Both students and practitioners provided valuable feedback on suggestions to improve the game. At present, data analysis is being conducted on the data collected from the game trial and surveys to determine how the game can be improved. To continue future development of the SafeSim game, a grant application was submitted to further improve the game and extend such research and case studies need to be done and provided.

6 Acknowledgement
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7 References


The use of building information modelling as a tool to improve informed design communication between student and lecturer

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Abstract:
Within the design studio at the Department of Architecture, Nelson Mandela University, timeous project submission is a problem. It was noted that students spent weeks on conceptual design ideas with no progressions towards completion. This study aimed to determine whether BIM, as opposed to the conventional method of design education, could be used to improve informed design communication during conceptual design for the first-year master of architecture students, contributing to timeous design project submission. The objectives for this research include understanding how BIM could improve the quality of information compared to the traditional method. The second objective is to evaluate the relationship between the use of BIM as design tool compared to a presentation tool to facilitate earlier design decision making and lastly to understand the relationship between project and time by using BIM throughout the design project. A cohort comparison rubric will be used as the method looking at the qualitative attributes of design intention, function, aesthetics, and sustainability. The 2016 cohort used the traditional method of design whereas the 2017 cohort used BIM, course was introduced in the computer module with implementation in the design studio. Findings include: Improved drawing type availability, accuracy, and quality, reduced time spent on redundant work and reduced printing cost. Based on upon the findings it can be concluded that BIM has the capability to improve the communication between student and lecturer in the conceptual stage, leading to a timeous submission. Recommendation; that BIM education must be incorporated in the undergraduate programme which will allow students the platform to express conceptual ideas more effectively within the design course.

Keywords:
Architectural Education, BIM, Communication, Conceptual Design.

1 Introduction

Vitruvius et al. (1960) states that Ferdinand de Saissure made a good point when he said: “Let him be educated, skilful with the pencil, instructed in geometry, know much history, have followed the philosophers with attention, instructed in geometry, understand music, have some knowledge of medicine, know the opinions of the jurists and be acquainted with astronomy and [with] the theory of the heavens.”

The philosophy of architectural education can be adopted as a dynamic process that engages with both the profession and society, grounded in humanism by means of critically engaging with concepts of reasoning at both emotion and intuition level. Studio-based education is one of the most common teaching methodologies in traditional design fields and especially in architectural education. The studio is essential to the students, for carrying out design work as well as for enhancing learning in sharing competences. Given the above, the role that communication plays in the development of an architectural student in the design studio is of utmost importance and in particular, the tools to achieve this become critical to their ability to succeed.

The lecturer noted a familiar pattern emerging in the design studios at the Department of Architecture, Nelson Mandela University, where students were failing to complete studio-based design projects on time. Throughout the year, design submission deadlines were not met, or only partially met, leading to a situation where at the final examination some projects were still incomplete. Time management was the easiest reason to explain why students failed to complete projects on time, but the problem appeared to have a deeper explanation. This appeared to lie in the design communication skills between student and lecturer during the conceptual through to the design development stages of a project. Widely used in the studio for teaching design is the conventional method (Saghafi et al., 2015). However, the tool that is today playing a significant role in transforming the overall quality of the design process is building information modelling (BIM). (Kim, 2012). Within the Department, BIM concepts are taught in the Architectural Computer Usage (postgraduate) module with little or no integration in the design studio.

The aim of the research is thus to investigate how BIM, as a design tool, can improve student-lecturer communication during the conceptual design phase of a project by integrating the BIM content from the Architectural Computer Usage module in a design studio project. The objective for this research involves the ability to improve the quality of information compared to the traditional method. The second objective is to evaluate the relationship between the use of BIM as design tool compared to a presentation tool to facilitate earlier design decision making and lastly to understand the relationship between project and time by using BIM throughout the design project. The study was conducted in the Department of Architecture at Nelson Mandela University within the first-year Masters in Architecture programme. The students in the programme had already obtained the basic practical knowledge of Autodesk Revit software during their undergraduate education and therefore the study is focused on the use of the software to inform the design process within their major module, Design 4.

2 Education - Approach or Technology

2.1 The Development of Architectural Education

The first approach to architectural education was in the form of an apprenticeship. The master and pupil relationship combined self-directed study and close observation of historical precedent (Ostwald & Williarns, 2008). The Ecole des Beaux-Arts education in France was the first model that used an alternative approach to apprenticeship based on four primary elements: the Ecole, private ateliers, the Salon and café life (Rezaei et al., 2013). The principle of success breeding success was adopted which created a strict hierarchy. The atelier was the studio where design was finalised for the competition and exhibition. The Salon was the annual exhibition where the best student work, handpicked by an elite jury, was presented to the public. The Ecole is described as the study of classical painting and architecture. The Atelier or studio was the first model that used an alternative approach to apprenticeship based on four primary elements: the Ecole, private ateliers, the Salon and café life (Rezaei et al., 2013).
With the technological changes occurring during the Industrial Revolution before World War I, a second approach, the Bauhaus education, was created in Germany. The Bauhaus education approach differed in that it brought together the artist and craftsman, using art and technology together. The Bauhaus school was the first educational model that introduced a curriculum to the architectural education system (Boyraz et al., 2017). In 21st century South African architecture design education, the Beaux-Arts approach is still evident as the form of the design studio.

2.2 The Conventional Method (CM)

Pen and paper was the drafting procedure for centuries before the development of the personal computer that automated drafting processes through computer-aided drafting (CAD). Traditional designs were 2D drawings with each building component generated by the architect. The relevant expert or consultant participating in the project used their own analytical process to complete them, re-entering the data. This process of manually entering and changing data was time-consuming and had a direct influence on the timeframe of the building process and decision-making. 2D drawings, made up of vector-based lines, are not capable of representing the actual building design information e.g. doors or windows, requiring a level of understanding and interpretation of 2D within a real 3D environment. The CM thus holds limitations as analyses is carried out separately and is prone to errors whilst being a painstakingly slow process, liable to be misunderstood or misinterpreted.

2.3 Alternative Method: Building Information Modelling

Today the profession is moving away from a two-dimensional method of working and more towards intelligent modelling (Takim et al., 2013). The main approach is building information modelling (BIM) which acts as a tool to promote project information sharing among industry professionals (Ahn et al., 2013). Mutual exchange of data results in a complete digital description of the building project, created by using standardised objects ensuring information in the model will be uniform with no discrepancies. Compared to a traditional 2D design process, BIM models contain information that is rich in physical and functional characteristics pertaining not only to construction documentation but also to the project life cycle.

Introducing BIM into the academic programme offers a number of advantages for the student, lecturer and employer. Two of the advantages noted were: Graduates with BIM training and expertise in the process and workflow are more employable compared to students without or with little BIM knowledge and, BIM can be the platform to bridge the traditional silos of AEC focusing on design and the design process (Eadie et al., 2011; Rooney, 2013). Three prominent challenges face the implementation of BIM education into architecture education, a lack of BIM expertise, resistance from academics and the existing curriculum (Kim, 2012).

2.4 Communication and Architecture

According to Hayes (2014), an architect needs analytical, communication, creativity, critical-thinking, organizational, technical, and visualization skills. Self-management skills speak to one’s personal characteristics, while special knowledge are skills you have that may not necessarily pertain to your career. Although architects make use of many visual means to communicate their ideas and intentions, it is important that architects (and architectural students) must learn how to listen, speak and write to communicate well-informed information effectively.

3 Research Methodology

This study adopted a mix-method research design that seeks to describe, decode, translate and focus on a phenomenon in its natural setting (Mouton, 2011). Action research (AR) was adopted as a methodology for this study. Costello (2003) explains that action research has a practical and problem-solving emphasis carried out by individuals, professionals and educators with the aim to improve education practice. Action research places high importance on involving its participants in the study (Welman et al., 2005).

Mills (2014) describes various methods used to gather data such as observation, interviews and documents. The study follows an observation strategy with the primary data collection a cohort comparison that enabled differences between the CM and BIM method of working to be documented. The cohort comparison aim was not an analysis of the design quality, but rather the ability to transfer information and communication. Prior to the cohort comparison, the researchers used a questionnaire to collect data from the first-year master of architecture students in order to determine their perception of architectural education. The students’ perceptions enabled the researchers to establish the basic areas of study used in the observation that followed.

The study adopted a descriptive analysis approach making use of coding (Creswell, 2013; Welman et al., 2005). The literature study established the core outcomes of the design programme as well as the requirements to participate in a critique session. Both sets of information created the outline for weekly critique observation and analysis, making use of the evaluation framework shown in Table 1 to measure to what extent the student met the requirements for the critique session.

<table>
<thead>
<tr>
<th>Evaluation Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design Intention</td>
</tr>
<tr>
<td>Layout</td>
</tr>
</tbody>
</table>

The researchers adopted a capability factor approach to analyse the cohort as the research is focusing on whether the BIM method is capable to improve communication compared to the traditional method within action research. Due to the research quest Robeyns (2003) states that a capability factor approach is a broad normative framework for design and evaluation. The specific focus is on informed information and communication as well as how BIM addresses the quality of informed design communication between lecturer and student in the conceptual design phase. This approach adopts the creation of a framework for evaluation method by using the six attributes that define quality information. Table 2 provides a synopsis of the attributes.
42nd AUBEA Conference 2018: Educating Building Professionals for the Future in the Globalised World

Table 2. Attributes defining quality in architectural design from the literature review

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Responsiveness</td>
<td>Establish requirements for project by means of critically engaging with all the issues pertaining to the building type, accommodation and site issues. Responsiveness furthermore relates to the massing response to the information gathered during the information development stage.</td>
</tr>
<tr>
<td>Relationship</td>
<td>The ability to associate, link and connect not only different building components and spatial planning (1) but to connect the design in different design platforms (2) and communicate building placement relationship, orientation and site relationships.</td>
</tr>
<tr>
<td>Modification</td>
<td>To what extent the design can be modified with ease or difficulty to explore design possibilities (flexibility).</td>
</tr>
<tr>
<td>Accuracy</td>
<td>The exactness or closeness of representing the building design information</td>
</tr>
<tr>
<td>Intelligence</td>
<td>The ability of an object to know and identify the real world-building the component is representing</td>
</tr>
<tr>
<td>Representation</td>
<td>The ability to define and communicate design process</td>
</tr>
</tbody>
</table>

The capability factor scoring is summarised and described in Table 3.

Table 3. Capability factor scoring

<table>
<thead>
<tr>
<th>Capability Factor</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Applicable</td>
<td>0</td>
</tr>
<tr>
<td>No Capability</td>
<td>1</td>
</tr>
<tr>
<td>Minimum Capability</td>
<td>2</td>
</tr>
<tr>
<td>Partial Capability</td>
<td>3</td>
</tr>
<tr>
<td>Complete Capability</td>
<td>4</td>
</tr>
</tbody>
</table>

The participants for the survey were all the first-year postgraduate students (4th yr of study) for both the 2016 and 2017 cohort, to reduce the influence of another module or course on the participants. From these participants, nine students were randomly selected to participate in the cohort study, a third of the class. The 2016 cohort used the CM to design. For 2017, BIM was introduced into the Architectural Computer Usage 403 module and integrated into the Architecture and Ecology design project. The nine students from both the 2016 and 2017 cohort were observed weekly, with the work analysed after each submission based on the information presented.

4 Findings and Discussion

The aim of the survey was to measure the students’ understanding at the start of the Master’s programme, thus understanding their perceptions as a whole. The majority of the students who participated in the survey obtained a Bachelor’s degree in Architecture (96%), with the exception of two students with a Bachelor’s degree in Technology (Applied Design). 85% of the students were graduates of Nelson Mandela University with the remainder coming from other South African Architectural programmes.

35% of the students said they always met the design deadline submission on time, with a further 22% stating they did this often, leaving nearly 50% who only met it sometimes or rarely. When asked if they believed they met the design submission requirements, 65% of the students were of the opinion they did not. When asked as to why they did not meet the timeous submission of design information, based on reasons described in the literature, students, to a greater extent, were of the opinion that excessive design assignments and a stressful programme contribute to the non-submission of design projects. Furthermore, students state that they engage too often for days in the design studio, where they become dependent on studio staff to come up with ideas and even resolve some of those ideas, which results in them struggling to pull into the design studio information learnt in other modules. When asked when they felt the most pressure, a mean score of 3.70 during the design development and 3.67 during final presentation reinforce the idea that the students do not understand the importance of the inception and concept stage of a project. As a result, they do not maximise this to improve their submission rate for projects, a pattern also noted in the literature.

The study then asked students about their use of BIM and software within the Design Studio. A mean score of 4.02 indicates that students use Autodesk Revit between some extent to a greater extent. In order to confirm or deny the statement made by various scholars (Green & Bonollo, 2003) that the CM is time-consuming, students were asked to indicate which techniques were in use; 85% of the students indicated they make use of hand drawings/sketches whilst 49% indicated that physical concept models are used to assist in communicating their ideas, both of which are CM techniques. The majority of the students (50%) make use of AutoCAD, which is CM in nature, with only 29% making use of Revit. Although 84% of the students fully agree that there are more tasks assigned to students and they are not looking to use BIM based on the current studio method.

The student work (models and drawings) in the cohort comparison adopted a rubric that focused on the qualitative attributes of design intention, function, aesthetics and sustainability. To be able to discuss the data and present in a consistent manner the researchers used a capability factor to describe the attribute’s ability to enhance information and ultimately improve communication.

Four prominent themes emerged from the cohort comparison study when assessing the Responsiveness attribute. The first concern with the 2016 cohort is that there was a lack of critical engagement with the project due to the lack of a proper accommodation schedule. This affected students’ ability to produce adequate work to bring to a critique session, and therefore students did not participate in critique sessions. In contrast, the students who made use of the BIM method immediately produced an accommodation schedule, containing both list of rooms as well as spatial data relating to the different spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed three-dimensional discussions to happen, with a range of drawing types produced. The CM confined students to their own ability to produce individual drawings. The CM cohort kept sustainable principles to generic spaces. Furthermore, communication in the CM were one-dimensional isolated discussions whereas the BIM method allowed th
The working method in BIM was graphical in nature enhancing the representative nature of the information produced by the student. This allowed students to shift problem solving to as early as the conceptual stage, leaving time to develop the project in more detail as compared to the 2016 cohort, improving on its Accuracy. Accuracy was achieved as BIM objects were assigned with parameters, which remained throughout the project. Notification, in the form of warnings, were given as soon as objects were not aligned with existing objects in the model. In contrast, CM students were making use of manual tools (pen and paper or drafting techniques) with the level of accuracy limited to the student skill level. Objects were redrawn or copied and with this multi-layer process, the level of precision was impacted. Objects are seen as individual lines with no fixed relationship to each other. Furthermore, the exclusion of objects or lines occurred regularly, as they are independent objects, which required manual checking against previous work or drawings. Drawing sets were incomplete with a large number of missing drawings, the majority of which were site plans, elevations, and sections. CM was error prone owing to the manual nature of the process whereas BIM made use of parametric design principles, which indicated any errors as they happened in real time, thus it scored four versus one for CM. When it came to Intelligence, CM holds no capability to indicate intelligence. The attempt to indicate sustainable and site information remained at the site investigation stage. Conceptual design proposals or mass models indicate building shape, but do not indicate the solar or sustainable outcome of the chosen building shape. There was no relationship between the drawings produced and the intelligence of the drawings with sustainability factors not included as they required manual calculations. The BIM method used conceptual mass models containing site-specific placement, which was linked to a global mapping service (Google Maps). By including this, detailed information regarding site solar information was used as a design tool that shaped their design proposals. With the use of shadows and solar analysis, the students constantly considered every design move they took by considering the physical conditions. Wall objects were given a height component which if changed enabled all assigned smart objects to change simultaneously. CM had No capability [1] and BIM had Complete capability [4].

Lastly, Representation plays a major part in communicating ideas and proposals to relevant parties. The nature of CM representative material varied from sketches in sketchbooks, conceptual models or basic line drawings. The process of gathering the illustrative material was manual: the student had to prepare each drawing individually with information developed over and over for each drawing. By not including plans or 3D material, it was difficult to engage with the students’ ideas or proposals, which led to miscommunication and even frustration in certain cases. Owing to the digital nature of the BIM working method, different views could be selected by the students to communicate the idea to the relevant staff members. The BIM model could be used with 3D printers or laser cutting machines to create rapid three-dimensional material for inclusion. The result is that the BIM method yet again showed Complete capability [4] whilst CM achieved the Minimum Capability [2] score.

The cohort comparison study identified four prominent themes, namely: competences, relationship, time and non-participation. The first theme, competences of the CM method and BIM method in relation to quality of drawing techniques, accuracy and availability of drawings, showed students clearly prefer working with hand sketches (78%) and physical models (47%) during the concept and conceptual design development stage of the project, then move to computer software as a production tool. The 2017 cohort predominately made use of BIM as a method with remarkable changes in the quality of

<table>
<thead>
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<th>Responsiveness</th>
<th>2016 Cohort</th>
<th>2017 Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>No Capability</td>
<td>Complete Capability</td>
</tr>
</tbody>
</table>

With respect to the Relationship attribute, the research outlines five critical areas. The main issue was around the drawing techniques used by students who made use of the CM method, which inhibited legibility, whilst the BIM method uses a universal drawing technique, promoting legibility. Communication and discussions around the internal and exterior relationship promoted by the well-informed relationship information produced by the BIM cohort, whereas with the CM cohort, no relationship information was evident. The CM’s were error prone due to individual capabilities and therefore drawings did not correlate, whereas the digital manner of BIM allowed drawings to correlate and cross-reference to other drawings without any errors being evident.

The CM thus hinders the relationship between structure and spatial planning due to a lack of information, as the construction method is an afterthought compared to BIM, where students must consider the construction method as part of the spatial planning. BIM allowed for the relationship between different platforms without rework whereas for the CM, moving from one platform to another required starting over. The 2016 cohort indicated an isolated one-dimensional engagement as opposed to the four-dimensional engagement showcased by the 2017 cohort making use of BIM. The relationship to associate, link and connect design platforms was lacking from the 2016 cohort whereas the 2017 cohort engaged with good drawing techniques, the relationship between spatial and construction methods and linking of design platforms. As a result, the 2016 cohort achieved a minimum capability rating [2] compared with a complete capability rating [4] for the 2017 cohort.

Modification promoted communication as BIM models used by the 2017 cohort enabled easy modification, timely meeting critique sessions, whereas the 2016 cohort did not meet critique session deadlines, modifications being unavailable. Owing to the nature of CM being hand-and-paper or basic computer drafting orientated, modification of the design proposal was a manual process. The proposal needed to be redrawn with every reiteration, which in many instances also included a redraw of existing site works. With the use of BIM by the 2017 cohort, drawing techniques improved whilst errors reduced, making legibility easier, with the availability of a range of drawings at different scales. Design communication between both parties focused on the design, not less important discussions. This is evident in the error-prone, weak drawing technique and lack of detail which were produced by the 2016 CM cohort. When BIM was used as a design tool by the 2017 cohort, three-dimensional complexity, exploration of design ideas and the evaluation of the design proposal were explored. Making use of parametric design requires the input of construction techniques from a very early stage to influence the design decisions. The 2016 cohorts’ manual nature of working indicated material or structures without critically engaging with construction techniques and the influence on design decisions. CM requires manual modification of objects versus the parametric nature of BIM, thus the 2017 cohort scored four to 2016’s two.

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drawings produced for critique sessions, particularly with regard to spatial relationship between 2D and 3D drawings. The techniques used by the 2017 cohort included information-rich drawings, which assisted in communicating the design project to studio staff. The CM used by the 2016 cohort inhibited the exchange of information between lecturer and student. The level of accuracy was left to the ability of the individual. The drawings contained mistakes, or were either unclear or too diagrammatic for the lecturer to understand. Owing to the intelligent nature of the method, the BIM model enabled drawings to be updated and modified with ease without causing any confusion. The virtual nature of the method allowed the 2017 cohort to communicate the design process on multiple levels owing to the embedded data inside the model, with drawings available on demand.

Relationship, second theme, with regards to undefined project information, isolated spatial relationship, and structural relationship. The 2016 cohort failed to produce an in-depth accommodation schedule, which reduced the quality of massing material for discussion between project parameters and spatial orientation. A quantitative and qualitative accommodation schedule was produced by the 2017 cohort, which assisted them to complete a mass model by the first critique session. Isolated discussions were a major concern during the critique sessions of the 2016 cohort. Information was restricted to plans only with no sections or elevations. Information, furthermore, was not contextualised and drawings and models were seen as floating objects. The use of conceptual design models by the 2017 cohort enhanced the nature of the project, design outline and site information, compared to the verbal nature of the 2016 cohort’s use of 2D diagrams during conceptual critique sessions. The 2017 cohort made use of BIM models, which assisted the inclusivity of information with the use of site-specific solar information. Owing to the lack of construction information available during the 2016 cohort critique sessions, the engagement between spatial planning and structure was not evident until the week before final submission. The 2017 cohort, however, included construction methods as well as material usage from an early stage in the project. The combination of structure and spatial planning allowed for the full development of the project.

The third theme is structured around the time factor and finance. The cohort comparison found that during the five weeks of the project, the 2016 cohort spent, on average, 220 hours working on it. The 2017 cohort spent 126 hours on average on the same project. Thus students spent 47% less time on the project owing to the use of BIM, providing students with time to focus on other modules. The students indicated that daily living and programme costs do have a direct impact on participation in design critique sessions, as students regularly do not have the money to print, or reprint, model or re-model work for critique sessions. The fourth pertinent theme is non-participation, categorised as design complexity and ‘what if’ scenarios. BIM’s virtual modelling capability communicate 2D and 3D complexities simultaneously aiding critique participation. With the introduction of BIM the decision-making process shifted to the conceptual stage of the project enabling the detection of any “what if” scenarios upfront. In addition, the transition from conceptual design-to-design development is more linear in nature due to the parametric ability of the design objects. The 2016 cohort had a break in the process due to hand drawings and models needing to be translated into digital formats for presentation purposes. This indicates a break in thought processes using CM between the early development of the design and the formal expression of the project, in other words, as a design tool versus a production tool.

5 Conclusion and Further Research

The data gathered at the start of the study indicated that there is an inability to communicate during critiques sessions between student and lecturer. The Building Information Modelling Method assisted students and staff to improve on this, providing the capability to improve the information produced based on design quality attributes, responsiveness, relationship, modification, accuracy, intelligence and representation, indicating an improvement in communication between lecturer and student during each critique session. The CM limited the exchange in the quality attributes of information produced by the students, hindered the production of well-informed sets of information, and did not improve the communication between student and lecturer. This suggests that BIM allows for improved communication between student and lecturer compared to the CM. The suggestion is that the 47% time saving by students on submissions shows a greater efficiency using BIM, which would have a marked impact on the number of students submitting on time.

Recommendations include that the Department of Architecture revisit the computer module, and in particular the content structure of the module, when introduced in the second year of the Bachelor of Architectural Studies. A dire need exists for research into the impact of BIM on the pedagogy of architectural education that will positively change education and the profession in South Africa. The department should reconsider the method through which architectural students are educated in the design studio, by enhancing design communication during critique sessions through the intervention of BIM, addressing decolonisation of the pedagogy and relating this to the needs of the African Architectural professional. This study revealed that using the BIM produces well informed design information, which if used during conceptual design critique sessions would enhance communication between student and lecturer.

6 References


Abstract:
Identifying success agents is a controversial subject amongst construction stakeholders. Success is often measured by definitive factors such as on-time and on-budget completions, work quality and safety benchmarks. Nevertheless, there is no universal agreement on the definition of project success in literature. The purpose of this paper is to articulate extant views on success factors in the construction of marine infrastructures. It shows there is only a thin line between failure and success in marine projects, and that both go together to the benefit of project deliverables. The concept of collaboration is used to explain this, using unique attributes of marine project (e.g. dynamic conditions and uncertainty) and how they impact stakeholders’ satisfaction. Conclusions are drawn from literature by focusing on frameworks that could assist stakeholders in marine projects, and the research community on project management, regarding the management of success and failure in marine projects.

Keywords:
marine projects, project management, success factors

1 Introduction
Satisfaction is paramount in construction projects. Where this is impossible to achieve, failure imminent. Evidence in construction management suggests clients are most dissatisfied if their projects failed to achieve the benchmarks relating to costs, duration, quality and safety that they might have set at the beginning of their projects (Flyvbjerg, 2007; Flyvbjerg et al., 2004; Pinto and Slevin, 1988). In the view of Davis (2014), projects are not successful unless their stakeholders are satisfied, irrespective of whether such projects performed to prescribed costs, schedule, quality and health expectations. But who is, or is not, a stakeholder in construction project management, and how can their satisfaction be measured, when and why? These are crucial questions that will help understand the true meaning of success and the factors that promote it in marine projects.

Success factors are well reported in normative literature relating to construction project management (Larsen et al., 2016; Peetawan and Suthiwartnarueput, 2018; Porter and Parker, 1993). It is evident most studies on the subject are not specific to project environments. They seldom address the uniqueness of projects either, marine construction projects in particular. Karami and Olatunji (2018a) have outlined the uniqueness of marine projects. Amongst the attributes they identified are uncertainties, safety issues, terrain constraints, complexity of design and construction methods and limited access to support infrastructure. These often mean marine projects are more challenging than conventional projects. Success factors in them are not likely to be entirely the same as

References:
conventional projects’. Nevertheless, there is limited information on these in literature. Through a review of literature, this paper attempts to identify existing views on success agents in near shore and offshore construction projects. In addition, unique attributes of marine projects, their relationship with success factors and impact on stakeholders are explored.

2 Review of Literature on Success Factors

Industry practitioners and academic research often do not regarding causalities of project success (Prabhakar, 2009). As a result, criteria by which success is define are still a subject of controversy (Baccarini, 1999; Freeman and Beale, 1992). Project stakeholders are required to adapt in a competitive construction industry unless they are able to visualize and develop their strategies in line with key success factors that are important to them (Ketelhöhn, 1998). Utilizing specific strategies based on success agents will distinguish stake holding entities in construction market and helps to improve the project’s function and value. It is important to recognize the characteristics of the environment in which success factors are employed.

Dvir et al. (1998) highlight the inappropriateness of an embracing model of success for all types of the projects. The underlying reason behind this theory is the considerable diversities and dissimilar scope of work amongst different projects. Dvir and his team underline the necessity of visualizing the relative significance of key success factors in a specific sector, and against issues they might be capable of preventing and correcting. Likewise, other authors have identified some attributes that help define success agents. These including project complexity, scope, size and the client’s familiarity to design options (Parfitt and Sanvido, 1993). Davis (2014) emphasises on situating stakeholders’ satisfaction indicators while evaluating the project’s success utilizing key success factors. Collaboration is a success agent also (Nzekwe-Excel, 2012). It impacts projects and ameliorates participants’ level of satisfaction.

2.1 Success Factors in Construction Projects

Eliciting success factors based on the projects domain and environment is to the best interest of stakeholders. This will help them to envision issues and determine the likelihood of potential success in projects. Entire scholarly material believe in usefulness of key success factors as the best common approach to address the probable issues. Despite all the controlling approaches, yet projects struggle with schedule overruns, cost overruns, safety and quality issues. Success factors can be determined by good understanding of the relationship between unique attributes and their impact on project’s satisfactory level, particularly in terms of overruns. (Chan et al., 2004) emphasis on project scope factors as affecting agents on project success including type, size, complexity and attributes of the project. Addressing diverse challenges in construction projects requires a procedure to visualise and identify success factors in different phases of the project lifecycle. Practical solutions as a result will ameliorate the efficiency, diminish the overruns and add value to the project. By reviewing 43 articles, (Chan et al., 2004) classify critical success factors in five categories including environmental factors, management strategies, project approaches, project related factors and project’s team related factors.

In recent past, researchers and industry practitioners have put too much effort in minimizing the difficulties caused by complexity, uncertainty and dynamic nature of large projects. The challenge of developing a successful accomplishment framework has become a subject of controversy for many researches and industry experts (Duy Nguyen et al., 2004). In other words, stakeholders and project participants still struggle on how to outline an integrated structure for success agents in large construction projects. Davis (2014) argues that there is no universally agreement on project success factors among construction practitioners which outlines the significance of precise research and study in this area.

Considering wealth of literature, (Duy Nguyen et al., 2004) identify five main success agents for construction projects namely, proficiency of project manager, financial soundness through different stages of the project, appropirate multidisciplinary team, liability and commitment of team members and adequate resource allocation. Decisive role of human is the underlying component in all these factors which articulates the need for precise employment procedure. Considering the uniqueness of marine construction projects, accessibility to adequate specialties in different disciplines can be considered as a challenge for stakeholders. Comparably, (Walker, 1995) highlights the efficiency of construction team as a success factor for up-to-schedule completion. Moreover, author determines schedule performance along with quality and final cost as a pivotal success factor in construction projects. Affecting factors on schedule have been listed as complexity, scope and efficient management system. In Walker’s view, scope weighs more in regards to schedule performance as a success factor in construction projects.

According to (Gunduz and Yahya, 2015), eliciting and implementing success factors in construction projects ameliorates schedule performance and most likely prevents cost overruns. Similar to other researchers, author believe in necessity of evaluating the factor’s contribution on three particular criteria; quality, schedule and budget. (Sanvido et al., 1992) indicate that Successful completion of a project is ensured by satisfying the affecting factors, entirely and meticulously. In other words, fulfilling the success agents and project success are in high correlation. de Wit (1986) outlines project aim and objectives as the best tools to evaluate the project success. Failure or success of a specific project is measured by the quality of the objectives’ satisfaction. By conducting a pilot study on some successful projects, author elicited six frequent measurement criteria to evaluate project success including financial performance, time performance, stakeholders’ satisfaction, serviceability, contractor fulfilment and project team satisfaction.

A large number of the literature interpret success in a project by indicators such as on-time and budget completion while keeping the quality to a satisfactory level. The question is how to identify and achieve success agents which guarantee an ideal accomplishment? (Sanvido et al., 1992) argue that it is achievable through assessing the projects individually and considering the unique attributes of each project enabling the project team to implement predictive and corrective strategies.

2.2 Situating Unique Attributes

Marine projects require extreme management strategies to undertake complicated activities in erratic environment. They need to be assessed according to their unique characteristics and against diverse range of factors. High level of uncertainty, high risk-level activities and extant of these types of the project intensifies this requirement. (Gudmethal, 2002) emphasises on implementing a risk-reducing mechanism as a success factor which decreases the uncertainty in some marine activities that might be affected by inclement weather. Author highlights efficient design as another success factor in marine construction projects which prevents any damage to the partially or totally completed structures. Due to multidisciplinary nature of marine projects, having a proficient team...
and protecting them by implementing safety regulations is considered by Gudmestad (2002) as another factor for a successful completion. He underlines the importance of realistic time allocation while working off-seasons to guarantee safe completion and prevent any schedule overrun due to loss of personnel and assets.

(Johnson and Tatum, 1993) identify marine construction as a particular part of the industry with high risk and intense investment involving in diverse fabrications including jetties, breakwaters, ports, wharfs, oil and gas platforms, bridges, under-water pipelines and outfalls. High-technology equipment, technical assessment of project procedures and efficient methodologies of construction are considered as success agents that improves the productivity of the marine projects while keeping the costs and risks at the lowest possible level. Unique characteristics of marine projects in design and construction phase requires technical competency and distinctive equipment. Author determines robust teamwork culture, technical proficiency and practical experience gained from similar projects as significant success factors in marine construction projects which enhances the organisational structure of the contractors in long term.

Different types of hindering factors affect marine construction, make engineering estimation complex and act as a barrier in construction phase (Johnson and Tatum, 1993). Each specific project possess its own circumstances requiring peculiar treatment. Equipment and crew might be endangered by inclement weather conditions and productivity can be affected by environmental factors such as uncertainty in geotechnical conditions. Marine construction projects are usually executed in regional areas which makes the geotechnical and accessibility difficult. Having a robust dedicated mechanism to foresee these issues is of utmost importance. Karami and Olatunji (2018b) argue that “Strategies such as dynamic time table, pilot study, plan-ahead technique and specially implementation methods” have the potential to be implemented in marine construction as critical success factors with the aim of performance improvement and ideal accomplishment.

Marine projects are highly relied on their staff in different disciplines. Johnson and Tatum (1993) underline efficient and skilful crew as invaluable assets of a marine construction company. In multidisciplinary environment of marine construction, success is not achievable unless through a goal oriented culture and commitment of involved staff. Efficient managerial strategy to coordinate the project is inevitable. Marine construction projects are in need of unique equipment and machinery. Marine contractors should either hire or buy them. Karami and Olatunji (2018b) outlines that “most high-end equipment required in marine construction are often booked out years in advance” which makes the scheduling difficult. Having an in-house machinery department is considered as a success factor which enables the contractors to plan ahead according to the project’s requirements. They can even develop and customize their equipment based on project’s specifications (Johnson and Tatum, 1993). Shortage in any of the unique equipment might result in a huge overrun in schedule and budget.

Tam (2012) adhere to Gudmestad (2002) regarding to theory of risk management strategies as the path towards successful completion in marine projects. Author outlines uncertainty in geotechnical assumption as the most common factor affecting marine projects. Similar to other researches, Tam believes in pilot studies at very early stages as a success factor to improve the project performance.

Challenging environment of marine construction requires a systematic approach to deal with all the uncertainties and fulfill the requirements of the project to desirable level, safely and without compromising the quality. Tang and Bittner (2014) determine value engineering as a systematic mechanism with the potential to evaluate issues and create innovative solutions suitable in uncertain marine environment. In other words, having a team of experts, experienced and familiar with marine construction as a value engineering team assists in different stages, ameliorates the performance and increases the likelihood of successful completion, on time and within budget. Samie (2016) emphasises on appropriate collaboration of different disciplines as a critical success factor in multidisciplinary environment of marine infrastructures. Younesi et al. (2017) conducted a case study in Abuazar oilfield located in Persian Gulf regarding risk assessment in oil platform construction phase. Authors outlined risk management as a predictive approach capable of foreseeing uncertainties in construction phase activities and resolving probable issues.

According to Abbasheek and Kumar (2017), integrating the experts’ knowledge in construction phase of marine projects leads to performance improvement and successful completion along with diminishing the likelihood of overruns. Selecting the most appropriate contractor through an adequate selection model will prevent any inaccuracy during construction phase of marine projects and results in an ideal project completion (Karami and Olatunji, 2018b).

3 Framework for future research design

Marine construction projects are immensely challenging (Johnson and Tatum, 1993). Unique characteristics in these types of projects demand momentous technologies to ideally accomplish diverse activities in an uncertain environment. Johnson and his team identify marine construction as a unique industry in which developed technologies such as pile driving and steel fabrication have been utilized reasonably. Johnson’s work underlines the high potential on adopting new technologies in this industry. According to (Tang and Bittner, 2014), Successful completion of a project in this high-risk environment requires a mechanism to determine practical success factors. Similar to other construction sectors, marine projects will benefit from visualizing success factors in achieving the projects’ benchmarks. Success factors in infrastructure projects are well investigated in normative literature. However, there is limited focus on marine construction projects. Furthermore, the correlation between success factors in marine projects and their impact on features such as schedule performance, productivity and cost overruns have not been reported well in scholarly works. Hence, it is high time to conduct research studies and develop further dimensions to the success factors other than those generic approaches in traditional research. Accordingly, a literature review was conducted to underline significant success factors in construction projects, fine-tune them based on marine environment scope of work and elicit applicable agents in marine construction projects. Prevalent success factors were determined based on a review of published articles. It is evident that some extracted factors through the review are common among other industries. However, considering the scope of work and unique attributes of marine projects, their implications are not similar. They apply in this environment differently. Consequently, future works must consider these nuances to attain the most prominent factors in this industry.

4 Implications

This paper sought to identify key success factors in marine construction projects by reviewing scholarly works on different success agents in construction projects. Based on the normative literature, most eminent factors were identified. Their level of significance
on project components has not been discussed in this paper. Identified success factors can be combined into underlying themes including (1) financial stability, (2) appropriate planning, (3) technical strength, (4) safety and risk related protocols, (5) implementation procedures, (6) design appropriateness, (7) lessons learned, (8) efficient management strategies, (9) ethical commitment of the team involved and (10) adequate supportive machinery department. It should be noted that no particular arrangement of importance has been considered in classifying the factors. Table 1 illustrates the grouped success factors under each theme.

Evaluating table above shows that success factors might appear in different forms in a project. They can be in the format of a strategy giving technical instruction to improve functionality of the components (e.g. Construction methods). On the other hand, they might be part of a strategy aiming at improving the project performance and reducing the probable risks in projects (e.g. Plan-ahead techniques). Some of the success factors are unique to the nature of marine projects and should be considered while undertaking specific tasks in erratic marine environment (e.g. Dynamic time table). Moreover, certain factors in marine construction can be considered as a privilege for contractors during construction and even at prequalification stage (e.g. In-house machinery department).

Intense investment, high technology and risk, complexity and uncertain environment in marine construction projects implies the requirement of a mechanism to envision the probable issues and implement preventive strategies. This will be achieved by considering unique attributes while investigating success agents. Unless this uniqueness is understood meticulously, the potential mechanism is unlikely to obtain successful completion. Hence, distinctive characteristics in marine construction projects can be applied as a tool to attach additional success indicators to the projects’ evaluation procedures.

Table 1. Success factors classification and grouping

<table>
<thead>
<tr>
<th>Underlying theme</th>
<th>Description of elicited success factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial stability</td>
<td>➢ Financial strength in different stages of project</td>
</tr>
<tr>
<td>Appropriate planning</td>
<td>➢ Adequate resource allocation</td>
</tr>
<tr>
<td></td>
<td>➢ Realistic time allocation</td>
</tr>
<tr>
<td></td>
<td>➢ Dynamic time table</td>
</tr>
<tr>
<td>Technical soundness</td>
<td>➢ Appropriate multidisciplinary team</td>
</tr>
<tr>
<td></td>
<td>➢ Adequate specialties</td>
</tr>
<tr>
<td></td>
<td>➢ Technical proficiency</td>
</tr>
<tr>
<td></td>
<td>➢ Value engineering team</td>
</tr>
<tr>
<td>Safety and risk related protocols</td>
<td>➢ Risk-reduction mechanism</td>
</tr>
<tr>
<td></td>
<td>➢ Implementing safety regulations</td>
</tr>
<tr>
<td>Implementation procedures</td>
<td>➢ Technical assessment of project procedures</td>
</tr>
<tr>
<td></td>
<td>➢ Efficient methods of construction</td>
</tr>
<tr>
<td></td>
<td>➢ Plan-ahead techniques</td>
</tr>
<tr>
<td>Design appropriateness</td>
<td>➢ Efficient design</td>
</tr>
<tr>
<td></td>
<td>➢ Pilot study</td>
</tr>
<tr>
<td>Lessons learned</td>
<td>➢ Practical experience gained from similar projects</td>
</tr>
</tbody>
</table>

5 Conclusion and Further Research

Identifying the best mechanism for successful completion of the construction projects has always been a concern for construction practitioners and academics. Due to extant of activities in this industry, there have been always underlying factors which need to be addressed. This study has reviewed Success factors in marine construction by focusing on concept of collaboration, using unique attributes of marine project. Furthermore, common success agents in marine construction projects have been elicited to obtain a framework which helps to identify potential success and failure in marine projects. Such a framework that could assist stakeholders in marine construction projects, and the research community on project management through foreseeing the potential issues that might develop in the life of a project and plan preventive strategies. This paper also tried to highlight the significance of considering scope and unique attributes in different types of marine projects and eliciting success agents based on project’s characteristics. Hence, Scope-related approach will be of interest to the stakeholders which facilitates the path towards successful completion. Such an approach will be even applicable in ongoing projects to resolve probable issues by predictive or corrective strategies. The next stage of this study is to further look into success factors and determine their empirical relative significance.

6 References


Educational Applications of Virtual Reality in Construction Management, Engineering and Architecture: Students perspective, impact, challenges and future agenda

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Abstract: Virtual reality (VR) is at the forefront of contemporary advancements and innovation in architecture, construction and engineering (ACE) education. However, the application and impact of VR within tertiary education remains relatively unexplored. Despite the affiliation of the ACE disciplines within its respective industries, few empirical studies have examined the potential for VR to integrate academia with site-specific practice. This study considers the innovative potential of VR in context of ACE teaching and learning.

The paper examines the impact of VR teaching modules created for the course, Industrial and Infrastructure Construction at the University of New South Wales. The modules were developed and implemented through collaboration with industry partners and a world class contractor. The paper is anchored in and reports on semi-structured interviews conducted among Construction Management students examining their experience and insights gained about student expectations, challenges and learning needs. With focus on VR teaching, the interviews interrogate the potential of VR to support and elevate the student’s engagement with construction process through an immersive experience. The paper unpacks the interview results to quantify the effect of technological innovation and industry partnership on student learning. This systematic data collection through interviews, surveys and questionnaires allows for a greater understanding of the student perspectives, learning processes and adoption behaviour. Key findings included students ability of willingness to learn, enthusiasm and increased level of engagement within course content. It will enhance further development and adoption of VR tools and associated activity-level. The study further considers the relevance of this teaching approach to allied academic disciplines, such as architecture, as well as industry led employee training. It thus speculates as to the advantages VR extending from education to economic deficiency and productivity.

Keywords: 360 Cinema, Augmented Reality, Education, Immersive Environment, Innovation, Technology, Virtual Reality

1 Introduction

Visiting construction sites is a valuable educational tool for teaching construction techniques. However, drawbacks including safety issues, difficulties in accommodating large numbers of students, interruption to the construction work, and the difficulty of transporting all the students to the site harness the feasibility (Ashford, Peter and Mills,
This paper will discuss the use of virtual site visits to obtain the learning outcomes of real-site visits without the drawbacks. The site visit covers excavation processes including the utilised heavy equipment.

A virtual environment was created of an excavation including excavators, trucks and compactors. This environment was incorporated into a learning environment to educate students on how the construction process is sequenced. It included both the ability to display detailed information regarding particular processes through activating various hot spots, and formative assessment items such as multiple choice questions to ensure the students are learning from the module. Students experience the module in class through the use of an Advanced Visualisation and Interaction Environment, which is a 360-degree stereoscopic immersive interactive visualisation system. This involves the students being in the centre of a 5 meter diameter, 2 metre high cylinder with multiple projectors displaying the virtual environment around them. This allowed the normal social dynamics of a classroom to be experienced in the module, rather than turning it into an individual experience and missing out on the educational benefits of a classroom situation.

This paper seeks to identify key benefits of the implementation of Virtual Reality (VR) in education purposes and further applications in the construction, engineering and architecture industries. Such implementation is key towards creating future success of universities providing both undergraduate and graduate students with a level of practical knowledge and development prior to immersing themselves into the ACE industry. Interactive collaborative 3D visualisation has had a definite benefit on the understanding and learning of student’s development in an immersive environment as seen in the study below. The authenticity of an education space created by the University of New South Wales, has allowed for differentiation in innovation within the architecture, construction and engineering (ACE) industry, to create and insinuate innovative learning in a risk-free environment. Undergraduate students have the opportunity to engage in an immersive learning environment using modules including underground spaces, site layout, piling process and footing construction. Complementing theoretical concepts in lectures and tutorials, the Advanced Visualisation and Interaction Environment seeks to give students a rounded practical experience to allow them to visualise key aspects in construction through engaging with a 360 screen.

The importance of this paper lays in the future advancement of education and development of innovation. Alternate methods of application including VR in the education space have testified the need and ability to influence and benefit students’ perception of real-life construction practices. This paper includes an analysis of literature review, explanation of research methodology, findings and discussion, areas of improvement, conclusion and further research and acknowledgement.

2 Literature Review

VR sets the cornerstone for advancement and innovation in ACE education. Recent literature has tended to explore the new application of VR in construction. However, the application of advanced VR technology for university education and industry training has received less attention.

Setareh et al. (2005) reviews potential applications of a virtual structural analysis program. Through the discussion of state of the art technology which has been developed at Virginia Polytechnic Institute for education and practical purposes. The program allows for the modelling of different elements under a variety of conditions along with earthquake simulations to evaluate structural stability. The paper discussed the utilisation of this software in several Virginia Tech Architectural courses. Feedback from students provided a qualitative measure of the effectiveness of the system. However, no quantitative approach was taken to measure the efficacy of the VR model. The preliminary qualitative results highlighted that the VR model can be used effectively in an educational environment as it provides a unique experiential teaching/learning tool.

The initial application of modern VR systems is discussed from a cross-disciplinary point of view by (Setareh et al., 2005). Its application within the vehicle simulation, transport, entertainment, design and medicine are discussed at length and serves to show how powerful a tool VR can be. Narrowing down to the field of architecture and engineering, the paper explores the idea that current VR visualisation tools are solely used for communication purposes between the client and the engineering team. Secondly, newer VR systems have focused on being able to train new architects and engineers on the theory behind design by exporting models from CAD packages. This highlights a large gap in industry whereby VR visualisation systems were focused primarily on the aesthetics and design ideologies as opposed to the technical and engineering constraints of the design. The VR model developed by Virginia Tech was a potential solution to fill this gap. Its design objectives were purely focused on allowing engineers/architects to create a structural model in a virtual environment and apply technical constraints to the design. Such constraints include: i) Structural loading (gravity); ii) Seismic loading; iii) Wind loading.

The models structural response to these factors could then be simulated and visualised in order to gain a stronger understanding of the consequences of certain building designs. The user is also able to modify the model at any point in the design phase and the results of the simulation will change accordingly. Finally, the research paper identifies that there are currently no known programs which simulate progressive collapse in buildings through methods such as creep failure, which this VR system is designed to correct. The application of such a tool is wide and varied however the paper focuses on two potential areas with which significant improvements can be seen through the application of this technology being: training of students in the building sciences industry, training of personnel for design and research within industry. Table 1 summarises the literature relevant to VR applications.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Method</th>
<th>Finding/Implication</th>
<th>Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enabling Discovery-Based Learning in Construction using Telepresent Augmented Reality (AR) (Behzadan and Kamat, 2013)</td>
<td>Undergraduate students used head mounted technology (HMT). Video stream of construction site was transmitted to and displayed in classroom. Students interacted with excavation and forklift modules.</td>
<td>Students from university have the ability to witness live streamed site conditions and interact accordingly, integrating state-of-the-art information delivery technologies into the classroom.</td>
<td>Importance and applications of augmented visualisation for education addressed, but the impact of modules was not measured.</td>
</tr>
<tr>
<td>AR in architecture and design: potentials and challenges for application (Wang, 2009)</td>
<td>The current and potential applications of AR within the ACE industries were investigated. Notable technologies included BUILD-IT, where the integration from design into technology included 3D models.</td>
<td>Benefits and suggestions in current systems of ACE industries were defined. Further research seeks to enable AR in potential applications to allow for a robust system.</td>
<td>Limitations in technology included 3D models. As applications currently reside through 3D models.</td>
</tr>
</tbody>
</table>
real as-built environment is seen. allowing for use in all environments. fixed/controlled environment.

| Identification of application areas for Augmented Reality in industrial construction based on technology suitability (Dunston, 2008) | Study undertaken to distinguish the appropriate applications of AR in industrial construction, based on interviews. Potential applications to increase performance were explored including excavation tasks. Study explores how AR has potential benefits in performance in industrial construction dependent to the tasks' suitability and arrangement. Results were recorded by academics at Purdue University. | Application of innovation and technology was placed in an industrial construction standpoint only. |
| Application of a Virtual Environment System in Building Education (Setareh et al., 2005) | Undergraduate and graduate architectural students at Virginia Tech experienced VR. Surveys and interviews conducted. Feedback from students’ who experienced the VR modules was recorded. Results indicated that the VR tool allowed solutions proposed by students to be tested instantaneously and can observe the effects of their solutions. | One student was interacting with the VR module and others were watching the screencast. Only focused on soft story and earthquake simulation. |

3 Research Methodology

This study aims to explore potential areas of ACE learning that can be improved by utilisation of new applications of VR. This study adopts an empirical approach to evaluate a course as a case study and employs semi-structured interviews. The course selected was Industrial and Infrastructure Construction (IIC), at the University of New South Wales. The IIC seeks to provide the opportunity to first year students with a cohort of 300, to engage in and synthesise concepts of industrial and infrastructure construction. The cohort consists of a diverse group of individuals inclusive of students with and without experience, international and local students. A semi-structured interview was conducted amongst construction students to learn their expectations, challenges and needs to enhance the learning activities. The interview also engaged students who partook in IIC and investigated how the sample VR modules give students the ability to engage and immerse themselves on site through VR. Inertia, quality of product and effectiveness remain the main factors which retard the use of Virtual Reality from becoming prevalent in the construction and engineering industry. This paper explains the effect of the use of VR on student learning, partnering up with an industry partner, a world class contractor, identifying the impacts and prevalent factors on students through leading processes.

The course materials, design, and online interactions were collected for a careful evaluation. In addition, the immersive materials produced for this course also were presented and evaluated. Then several students who had undertaken the course, have been recruited and interviewed to highlight the extent of impact through the topic questions attached in the appendix. The students ranged from first to penultimate students, ageing from 18-21, being both domestic and international students.

4 Implementation of 360° Video Modules

In addition to experiencing the virtual environment in the Advanced Visualisation and Interaction Environment, students were given access to 360° recordings of the construction environment. This format is accessible using any internet browser as the videos are hosted on YouTube. Each video is recorded in 4K resolution and allows the user to pan around the area of the recorded 360° space. This is done by pressing and holding down the left mouse button and then moving the mouse towards the direction of choice to pan the picture as shown in Figure 1.

![Figure 1. Panning of 360° sample module used for the case course.](image)

The main presentation format of the modules is using a cylindrical room, namely VR Cinema. Figure 2 shows how the module is running using a server computer in the room behind the cylindrical room. However, a tutor controlling the module including backward-forward, pushing the hotspots, and change the modules using a tablet in front of the students. This is so students have the ability to be become involved in running and managing the process of using the modules in groups of 15 which is the capacity of the cylindrical room.

![Figure 2. The main computer running the module in a separate control room.](image)
5 Findings

The effect of VR on students through the methods discussed; show an overall positive impact on learning and gaining a depth of knowledge in construction methodology and processes. Table 2 represents a summary of student interaction/experience through the 360 modules.

Table 2. Summary table of student interaction/experience from virtual reality and 360 module integrations

<table>
<thead>
<tr>
<th>The 360 module feature</th>
<th>Aims/Expectations</th>
<th>Students perspective / Examples from the course or student experience</th>
</tr>
</thead>
<tbody>
<tr>
<td>360° Cameras scanning site</td>
<td>Clarity within the lessons regarding construction excavation processes</td>
<td>“As I had no onsite experience, it was extremely interesting to see the scale, size and type of drilling and excavating equipment used on site. This included a man standing next to an immense piling rig, ultimately showcasing the mammoth operations undertaken on site.”</td>
</tr>
<tr>
<td>Activity Analysis</td>
<td>Recognizing the scale, size and type of drilling and excavating equipment</td>
<td>“The VR and 360 video was unlike any tutorial or learning experience I had seen. It engaged me in an interesting medium and I felt like I learned a lot, more than regular tutorials and lectures from other subjects within the Construction Management degree.”</td>
</tr>
<tr>
<td>Hotspots (See Figure 4)</td>
<td>Hotspots provide me with rich content emphasizing the significance of specific objects on site</td>
<td>“The quizzes allowed me to be engaged and active throughout the module to reinforce knowledge learned in an efficient method. Quiz questions tested knowledge including processes of footing construction, identification of PPE on site and methodology of productivity principles.”</td>
</tr>
<tr>
<td>Analysis of site activities/efficiency</td>
<td>Effective communication of course information</td>
<td>“Increased my engagement in learning”</td>
</tr>
<tr>
<td>VR Cinema room/Innovation</td>
<td>Authentic learning environment that immerses me into the excavation and piling process despite being physically inside a classroom</td>
<td>“After the VR room, I spoke with students within the cohort, who were both working and studying. They mentioned that if this concept was applied earlier within their careers further development could have been made. They spoke about the excavation and piling process and how it aligned with their current sites, highlighting its relevance.”</td>
</tr>
<tr>
<td>Quizzes</td>
<td>Increases my interest in learning the subject</td>
<td>“Impact in technology has allowed for 3D glasses to be used within VR labs, creating a degree of realism. Through these innovative methods of teaching we have students who have had an increase of interest in learning the subject.”</td>
</tr>
<tr>
<td>Use of 3D glasses and screens</td>
<td>Increases my interest in learning the subject</td>
<td>Innovation in technology has allowed for 3D glasses to be used within VR labs, creating a degree of realism. Through these innovative methods of teaching we have students who have had an increase of interest in learning the subject.”</td>
</tr>
<tr>
<td>Collaboration</td>
<td>Facilitated conversations with peers about excavation and piling regarding construction and excavation</td>
<td>“Using the 3D glasses and screens in a practical sense is seen in the course as both subjects complement the effective practical inclusion of mining modules.”</td>
</tr>
<tr>
<td>Interrelated Concepts</td>
<td>Helps to relate previous knowledge to new information about excavation processes</td>
<td>“It was great to see the whole operation of the footing system from the piling rigs drilling holes to the reinforcement being in place and finally in situ concrete being poured and capped off to create piles.”</td>
</tr>
</tbody>
</table>

From students perspective, by “becoming immersed” in Virtual Reality and 360 video, a greater sense of “motivation and drive to seek further knowledge on key site elements” has been evident. This includes active engagement within quizzes of the quarry module, where trucks were used to underline the importance of Personal Protective Equipment. The immersive environment is evident through Figure 3.

The modules provided to students have allowed the cohort to excel in “not just university but also the work place” by applying key aspects learned through the modules, in the field as a student describes. A student expresses:

“When I first stepped on site, it was a bit daunting. However, I quickly remembered key concepts of the site layout modules I learned in the VR labs and applied my knowledge to assist in site coordination and asserting the traffic management plan.”

Figure 3. The immersive environment used for the case course at UNSW

The VR lab allows for a greater insight into construction methodology expanding exposure to on site practices. Activities included underground mining modules, focusing on the array of different aspects involved. This directly complemented course content learned in lectures and tutorials where blasting of rock was seen and Shotcrete applied. This provides an insight of construction operations which occur mainly underground and cannot be seen unless on site. Subjects including Construction Materials and Building Structures at UNSW highlight the concept and theory behind the activity. However, visualization in a practical sense is seen in the course as both subjects complement the effective practical inclusion of mining modules.

This encapsulates students through an innovative medium to transfer vital knowledge about construction “safety, and scale of operations”. This includes “visualising a piling rig’s height in comparison to a human on site with appropriate PPE” as one student describes.

“The immersive environment is evident through Figure 3.”

The depth of knowledge can be seen as students have indicated the positive effect of VR in conveying construction methodologies and procedures.
A number of key benefits have risen from the application of VR. Students have the ability to investigate how “productivity measures” are taken place through 360° cameras. An example of this practice includes the number of cycles an excavator takes to fill a truck from bulk excavation. And through the alteration of key selections, the rate of productivity is evident highlighting the emphasis of efficiency on site, correlating to both cost and time savings. Students have a real feel of back of house cost and efficiency management which can be applied on site first hand in the field. Another benefit is the visualization of machinery in practice and how events occur simultaneously highlighting management which can be applied on site first hand in the field.

The concept of ‘peering beyond the hoardings’ highlights the unique experience of VR, producing “a depth of knowledge which cannot be gained unless on site” one student states. Thus, allowing for greater access to information, making students more employable by increasing knowledge and skill base.

Augmented interactivity throughout modules allows for the ability of potential future uses in construction including the potential training of employees on-site factors and materials handling, highlighting key services to mitigate risk prior to construction. Students may then forecast potential risks by identifying certain items and taking precautionary methods within quizzes to emphasize concepts as “productivity cycles” as a student of The University of New South Wales, Built Environment student describes:

“Through the useful incorporation of mini quizzes throughout the modules, we were able to cement our learning by solving key issues relating to site layout, piling process and footing construction.”

The VR applications were developed and tested for different purposes in architecture, construction and civil engineering. Most of the studies employs small groups without industrial professions involvements and they do not employ any based control groups, geared toward feasibility or proof of concept testing (Kim et al., 2013). While there are such limitations in the VR literature, there are much more deficiencies in the education literature since there are limited studies examining the effect of VR modules on students learning.

### 6 Discussion on Future Needs

At UNSW, Construction Management and Architecture programs operate side by side within one faculty; however, their curriculum remains entirely distinct and independent. The recent development of VR Cinema opened an unprecedented opportunity for cross disciplinary collaboration and exchange. Regulated and guided by the National Standard of Competency for Architects, architectural education in Australia is structured around four ‘units’ that broadly define the process of conception and delivery of an architectural project. These consist of ‘Design’, ‘Documentation’, ‘Project Delivery’ and ‘Practice Management’. As it has been outlined in this paper VR technology has been at the forefront of architectural training, however it is in the first unit of competency, that is ‘design’ in which this technology has been most pervasive. In subject areas oriented at the practical and technical dimensions of architectural production, and despite their embrace of emergent technologies, VR teaching tools are typically absent. And this is despite a consistent emphasis by the Competency Standards on the integration of practical realities within an architectural education. In units ‘Documentation’ and ‘Project Delivery’ for example, an in-depth knowledge of site specific construction processes and assembly systems is dominant. Historically this emphasis was addressed through the integration of ‘real life’ scenarios within the teaching curriculum.

Further needs through the integration of architecture and construction may therefore be developed in initial design documentation stage, where key stakeholders of a project team including architects, engineers, project and construction managers may collaborate to ensure serviceability is achieved. An example of this is superimposing services through layers of BIM through virtual reality to define runs of pipework and ductwork which not generally seen on same drawings. This would allow for the mitigation of potential risks in the outlay of services on site with services including HVAC pipes and hydraulic lines to run free from obstruction. Focusing on a ‘prevention rather than a cure’ approach, efficiency within this scope may be achieved with possible technology advancement.

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Key factor</th>
<th>Selected quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview of operations</td>
<td>Scale of the construction site</td>
<td>“It was great to see just how many vehicles and machinery are involved in bulk excavation and how many machines are operating around the site”</td>
</tr>
<tr>
<td>Deep understanding of construction operations</td>
<td>Predecessors of construction processes</td>
<td>“The twenty-minute modules allowed us to see the whole process of a piling rig from digging the hole to inserting the cage, in situ concrete and capping off, we were able to see the predecessors of the method”</td>
</tr>
</tbody>
</table>

Figure 4. A selected Hotspot Site Layout Interview - Bulk excavation.
Construction of one to one architectural components, even whole architectural structures were, for example, used to immerse the students to the realities of the construction site. With the rapid expansion student numbers, the limitation posed by Health and Safety and dynamic evolution of construction technique processes, such approaches are dismissed due to both economic and pedagogical limitations.

Potential integration of technology within training and development in employees may also be applied, allowing for a fast-tracked approach for new employees on site. Leading contractors have thus the ability to attract, train and retain staff by offering innovative methods to training which prove beneficial. Incorporating relevant modules including site layout modules for cadets within the industry to learn from key on site machinery and labour required.

The VR technology described in this paper has the potential to revitalise such teaching methods and surpass their limitations through collaboration with industry innovators and material specialists. It moreover presents cross disciplinary collaboration as a tool by which enhance core disciplinary competencies. A greater emphasis in understanding within the training and development of employees is a potential future outcome of this research through measuring the degree of efficiency and productivity adapted when streamlining new processes in a corporation.

The successful integration in applications of innovative technology through VR within the architecture, construction and civil engineering industry will lead to advancement. 360 capturing tools within the education immersive space at the University of New South Wales have identified promising benefits by undergraduate students. This concept of providing an authentic education space with interactive and engaging modules has seen an increase in a depth of knowledge and alignment with course content. Key selected benefits which were identified are: successful integration of theoretical concepts into practical experience in an authentic learning environment; fundamental safety principles identified with key safe on-site practices learned; assists in workplace integration with a number of students highlighting the benefits gained prior to learning and post working in the ACE industry. Further research in providing alternate applications within the education space are justified on the onset of this paper with potential applications in training workforce is viable. Through the successful utilisation of immersive technology in the work place, employers have the ability to fast track training mechanisms to increase productivity and efficiency.

7 Conclusion and Further Research

This paper presents the findings of evaluating a VR module implemented in a course at UNSW. The findings were discussed and further extended to give a direction for future studies. The findings show the importance of a series of factors influencing a greater depth of knowledge and awareness of onsite factors. Based on the relevant literature, few empirical studies have been conducted to examine the proposed integration of virtual reality in context to building construction sites. Systematic data collection through interviews allowed for an in-depth insight into the student’s perspectives and thought process. The results also provide a guidance to broaden understanding of users’ adoption behaviour within this context and thereby increasing the chances for successful adoption of VR innovation and develop activity-level. The study also offers the opportunity of employee training through a practical sense in onsite factors with the inclusion of potential future practices to assist in the productivity and efficiency rates for contractors having a definite time and cost saving.

8 Acknowledgement

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9 References


10 Appendices

Survey Questions –
- What were your expectations from the VR-cinema?
- Have you encountered this sort of technology before in university?
- Were you satisfied/dissatisfied from your experience?
- Looking back after 7 months, what has been the impact from learning the concepts in the 360 modules as you did?
- Does it assist your understanding of construction processes as a whole?
- What was your favourite aspects from the modules and why?
- Do you think it made construction methodology and concepts clearer? If so why?
- What subjects do you think complement or help assist in gaining a depth of knowledge?
- Would you be more interested in other courses if they had a concept like the Advanced Visualisation and Interaction Environment integrated to complement theory with practice?
- Looking forward, what aspects on the VR-cinema and 360 modules could be improved to assist in alternative applications?
Multi-objective optimization for scaffold on-site supply chain

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Abstract: Scaffolding construction has accounted for a significant proportion of the operational cost for a construction project due to its considerable demand on materials and workforce input. This paper aims to optimize the scaffold on-site supply chain through optimizing scaffolding project scheduling. A multi-objective optimization model has been established based on a practical scenario of a mega construction project with the objectives of minimizing the project duration and total cost and maximizing the utilization rate of workforce. A non-dominated sorting genetic algorithm (NSGA-II) is developed and applied for solving this complex problem.

Keywords: Scaffolding construction, project scheduling, multi-objective optimization, NSGA-II

1 Introduction

Over the last decade, especially in recent years, the worldwide business environment has become more competitive and the benefits of supply chain management (SCM) have been emphasized by both industry professionals and academic researchers. The supply chain of a construction project, known as construction supply chain (CSC), concatenates each component from suppliers, contractors to the project owners, and associates the flow of materials, equipment, resources and the transformation of information through each stage (Agarwal et al., 2006). The CSC has drawn a great attention in the construction industry as the need to tackle the challenges such as low productivity, excessive inventory, resource waste and inefficient management of materials has been recognized throughout the industry (Irizarry et al., 2013). Scaffolding system, as a kind of temporary structure applied in construction industry, provides the platform for material placement and supports workers for aerial construction activities (Raty, 1987). It is commonly known that scaffolding system would not be remained within the final construction structure, therefore, the importance and necessity of scaffolding construction management have not been realized by industry practitioners and researchers. In fact, scaffolding activities have a substantial impact on the safety, quality, productivity and total operational cost of a construction project. According to the report by Construction Industry Institute (CII), the construction and disassembly of scaffolding system has become one of the most wasteful components that contribute to the high indirect construction cost (Kim and Teizer, 2014). The evidence can be found in oil and gas industry in Australia. The maintenance cost of the facilities in a LNG plant is estimated to account for 11.47% to 15.36% of the total operational cost, and scaffolding is one of the main contributors as scaffolding materials are needed in a great demand for building supporting platforms (Cen et al., 2009), and approximately 10% of project budget would be assigned to scaffolding, while the proportion is still growing. The rental of scaffolding materials (leasing cost) is one of the prominent contributors to the staggering cost of scaffolding activities. As we know, the longer the scaffolding structures remain, the greater amount of expense would be spent by the project owner. In this case, appropriate planning of scaffolding construction and disassembly activities would manage to return the dismantled scaffolds timely and shorten the length of a project, which hereby reduce the leasing period of scaffolding materials. This leads us to the critical issue of scaffolding supply chain optimization - the project scheduling problem. Assuming the material demand of each activity is fixed, the schedule of activities would alter the total demand of the project in a given period which correspondingly affects the decision on material ordering. Consequently, project scheduling is the key to improve the performance of SSC.

In our proposed multi-objective SSC optimization model, multiple sub-projects and their corresponding scaffolding activities are considered which makes the problem more complex than a simple project scenario. The objectives of our model comprise minimizing the total duration and total cost of the project simultaneously, as well as maximizing the utilization rate of workforce. The total cost is broken down into several categories including material leasing cost, transportation cost and labour cost. By encompassing these aforementioned considerations, this SSC optimization problem has become a rather complicated and complex NP-Hard problem (Tavana et al., 2014). Therefore, an intelligent algorithm is proposed and applied to solve this SSC optimization problem. With the assistance of the proposed model and algorithm, project manager could manage a good balance among time, cost and resource utilization of scaffolding construction and disassembly.

The rest of paper is organized as follows. Section 2 describes the general scenario of SSC and presents the mathematical modelling of our proposed SSC optimization problem. Section 3 introduces the non-dominated sorting genetic algorithm (NSGA-II) for resolving our optimization model. A case study based on a real world project is conducted in section 4, and the conclusion of this paper is presented in section 5.

2 Literature Review

In this paper, a mega project that consists several scaffolding construction sub-projects is considered. For each sub-project, there is a set of activities that need to be conducted. Therefore, when the project manager commences the task of scheduling, two classes of priority relationships should be taken into consideration - the priorities between sub-projects and the precedence relationship between activities for each sub-project. However, these two classes of relationships are slightly different. The priority relationship between sub-projects in real life tends to be linear, and the sub-projects with higher level of priority would have the right to use the resources prior to other sub-projects. These sub-projects can be conducted at the same time. In our occasion, we assume that the sequence of operating these sub-projects is fixed. On the other hand, the precedence relationship between activities determines that the successors can only be carried out after the completion of predecessors. The SSC studied in this case would start from material suppliers and end at construction contractors or project owners, whereas scaffolding materials would be delivered directly from supplier warehouse to the project area and transferred around within the area for the operations of sub-projects. In addition, as a specific example of construction supply chain, SSC shows its difference comparing to the general CSC. The structure of scaffolding would be dismantled and returned to the suppliers, hence, the scaffolding supply chain starts from suppliers and ends at suppliers which makes it a closed loop supply chain. When the project starts, scaffolding materials will be delivered from supplier to the construction area based on the orders placed by construction contractors. Instead of transporting the whole amount of material demand, the construction contractors would normally order the components they need over a certain period in advance, they call this material ordering method as ‘drip-feed’ strategy. The quantity of material order is decided on the basis of the estimation of construction supervisors or team leaders. The scaffolding materials would not be shipped to working area directly, instead, they would be placed temporarily in a dedicated area, called ‘Laydown Area’. These inventory would be distributed to the workfront areas for each sub-
project and used for construction. Different from most other construction materials, scaffold materials are recyclable. When one of the construction project is completed, the scaffolding structure used would be dismantled and the components would be sent back to the supplier. In the operational flow of SSC described above, material ordering is vital to the management of scaffold inventory on-site and the control of total operation costs. As a matter of fact, if excessive amount of materials are ordered, high scaffold material leasing cost and inventory holding cost would occur. While on the contrary, not enough inventory would result in the delay of project. Thus, increasing the frequency of delivery would actually reduce the inventory on site at a single period. However, as a consequence, more transportation cost is expected. Hence, planning the best time and quantity for material delivery would ensure the operations being conducted on time by fulfilling the demand of materials with lower cost. In addition, in real life, the productivity of workers is not always consistent which would result in the variation of material demand from time to time. Therefore, in this paper, the assumption that the productivity for each scaffolding activity remains the same over its period. As a consequence, the material demand per unit time for each activity keeps stable over the activity execution period. The material flow in SSC is described as shown Figure 1.

![Material Flow of SSC](image)

### 2.1 Notations

The notations of our proposed mathematical model is presented in Figure 2.

#### Set and Indices

- \( F = \{f_1, ..., f_T\} \) set of scaffolding sub-projects indexed by \( f \)
- \( P = \{1, ..., P\} \) set of activities for each sub-project indexed by \( p \)
- \( r_i \subseteq r_j \) Immediate precedence relations among sub-projects, where \( (i, j) \in Y \), \( i \) indicates sub-project \( i \) must start after sub-project \( j \)'s completion
- \( r_i \subseteq r_j \) Immediate precedence relations among activities, where \( (j, k) \in Y \), \( j \) indicates activity \( j \) must start after activity \( k \)'s completion
- \( d_f = \{d_{f,1}, ..., d_{f,T}\} \) set of types of scaffold components indexed by \( f \)
- \( T = \{1, ..., T\} \) set of time slots indexed by \( t \) which represents time interval \((t-1, t)\)

#### Parameters

- \( r \) demand of scaffold component \( w \) for activity \( j \) in sub-project \( f \)
- \( s_j \) duration of activity \( j \) in sub-project \( f \)
- \( s_{f,j} \) workforce required for activity \( j \) in sub-project \( f \)
- \( l_{w} \) leasing one per unit time per unit weight for scaffold component \( w \)
- \( F \) labor cost per unit time per person
- \( q \) quantity of material delivery at time \( t \)
- \( p \) transportation cost per unit weight per mile
- \( T \) Maximum available workforce

#### Variables

- \( F \) project milestone
- \( a_{f,j} \) start time of activity \( j \) in sub-project \( f \)
- \( d_{f,j} \) completion time of activity \( j \) in sub-project \( f \)
- \( d_{f,j} = 1 \) if the activity \( j \) of sub-project \( f \) is executed in time \( t \\), otherwise \( d_{f,j} = 0 \)
- \( q_w \) the quantity of type \( w \) scaffold components supplied at time \( t \)

#### Figure 2. Notations

**2.2 Mathematical Modelling**

According to the problem described above, in order to optimize the performance of SSC for a mega project, an optimal scheduling for scaffolding activities should be designed. Hence, our intention in this Section is to construct a mathematical model for the integration of resource-constrained project scheduling problem in the scaffolding supply chain context. Time and cost are two critical indicators for evaluating the performance of the project management, while resource utilization, especially the workforce efficiency, is another importance consideration for project managers. Therefore, in this paper, a multi-objective mathematical model for SSC optimization problem is proposed with goals of minimizing the total duration and total cost and maximizing the workforce usage efficiency simultaneously. The multi-objective mathematical model of SSC optimization problem is presented as below.

\[
\min_{F_i} F_i = \sum_{t=1}^{T} (r^t - \sum_{f=1}^{T} \sum_{t=1}^{T} r^f)^2
\]  
(2.2.2)

\[
\min_{C_{\text{Total}}} C_{\text{Total}} = C_{\text{Lease}} + C_{\text{Labour}} + C_{\text{Transp}}
\]  
(1)

\[
\min_{F_i} F_i = \frac{1}{2} \left( \sum_{f=1}^{F} s_{f,j} \right)
\]  
(2.2.3)
Subject to

\[
C_{\text{Lease}} = \sum_{m=1}^{M} \sum_{j=1}^{T} \sum_{i=1}^{I} p_{ij}^m \cdot x_{ij}^m + \sum_{k=1}^{K} \sum_{j=1}^{T} \max(0, -p_{ij}^m \cdot x_{ij}^m) \cdot t_{ik}^m \tag{2.2.4}
\]

\[
C_{\text{Labour}} = \sum_{m=1}^{M} \sum_{j=1}^{T} \sum_{i=1}^{I} u_{ij} \cdot x_{ij}^m \tag{2.2.5}
\]

\[
C_{\text{Transport}} = \sum_{m=1}^{M} \sum_{j=1}^{T} \sum_{i=1}^{I} \sum_{j=1}^{T} M \max(0, -p_{ij}^m \cdot x_{ij}^m) \cdot \beta + \sum_{m=1}^{M} \sum_{j=1}^{T} \sum_{i=1}^{I} \gamma \cdot x_{ij}^m \tag{2.2.6}
\]

\[
x_{ij}^m = \frac{1}{T} \sum_{j=1}^{T} u_{ij} \cdot x_{ij}^m
\]

\[
s_{ij} \geq c_{ij} + 1, \forall (i, j) \in V_1
\]

\[
s_{ij} \geq c_{ij} + 1, \forall (i, j, k) \in V_1
\]

\[
c_{ij} \geq x_{ij}^m \cdot t, \forall i \in I, j \in J, t \in T
\]

\[
\sum_{i=1}^{I} u_{ij} \cdot x_{ij}^m \leq U, \forall i \in I, j \in J, t \in T
\]

\[
\sum_{j=1}^{J} p_{ij}^m \cdot x_{ij}^m \leq M, \forall i \in I, j \in J, m \in M
\]

\[
\sum_{i=1}^{I} x_{ij}^m = d_{ij}, \forall i \in J, j \in J, t \in T
\]

\[
x_{ij}^m \in \{0, 1\}, \forall i \in I, j \in J, t \in T
\]

\[
s_{ij} \geq 0, s_{ij} \geq 0, \forall i \in I, j \in J
\]

Equations (2.2.1), (2.2.2) and (2.2.3) represent the objective functions that minimize the total duration, the total cost and variation of workforce utilization rate respectively. The total duration can be comprehended as the latest completion time of the sub-projects, and \(s_{i+1}^j\) stands for the starting time of sub-project \(j+1\) which is an artificial node. The total cost consists of scaffold material leasing cost, labour cost and transportation cost. The leasing cost is charged for the scaffold materials either stored in the laydown areas or used for the construction. In another word, once the scaffold materials arrive the laydown area, leasing cost would occur. The labour cost is calculated based on the active workforce at anytime of the project and the transportation cost is the cost for delivering the materials from supplier to the laydown area and recycling the dismantled scaffold components back to warehouse. Equations (2.2.4), (2.2.5) and (2.2.6) represent the expressions of total leasing cost, labour cost and transportation cost respectively. In addition to the time and cost, the efficiency of resources utilization, especially the workforce arrangement, is a critical indicator for the performance of both project management and supply chain management. In the mathematical model, the fluctuation of workforce usage is expected to keep stable, which helps project manager to arrange appropriate number of workers on site and reduce the budget for labour cost correspondingly. The utilization rate of workforce at time \(t\) is shown in equation (2.2.7).

As aforementioned, in a mega construction project, some sub-projects need to be executed before the others because of the considerations related to locations, safety requirements and functions of different facilities. This kind of precedence relationship also applies to scaffolding activities, as there is a restricted procedure for scaffolding construction and disassembly. In our model, the precedence constraints between different sub-projects is considered, as well as the relationships between different scaffolding activities for each sub-project are taken into consideration, which are shown by the inequalities as indicated in (2.2.8), (2.2.9) and (2.2.10). Constraint (2.2.11) represents the resource constraint for workforce as the maximum number of workers that can be assigned to the project is limited. Constraint (2.2.12) ensures the demand of scaffold materials is always satisfied, while constraint (2.2.13) makes sure that every activity is executed. Constraint (2.2.14) and (2.2.15) are binary and non-negative constraints.

3 NSGA-II Algorithm

NSGA-II was initially introduced by Deb et al. (2002), which aims to search for a set of solutions that are sorted and organized in Pareto fronts (Deb et al., 2002). As aforementioned in the section of literature review, NSGA-II has several advantages compared to other evolutionary algorithm (EA) for solving multi-objective problems, such as fast computation, elitism incorporation and better convergence in the Pareto fronts (Ghoddousi, 2013). Traditionally, NSGA-II starts with an initialization procedure where a population of feasible solutions with size \(N\) is generated randomly, which is call the parent population \(P_1\). Genetic Algorithm (GA) operations - individual selection, crossover and mutation - are conducted for creating an offspring population \(Q_1\) from the parent population \(P_1\). A larger population \(R_1\) with size \(2N\) is then generated by combining \(P_1\) and \(Q_1\) followed by selection procedure using non-dominated sorting and crowding distance sorting to filter out the population of elitist individuals with size \(N\). Non-dominated sorting is the procedure of ranking the individuals into different fronts with different non-domination levels, while crowding distance sorting refers to the ranking between different individuals in a front (Mohapatra, 2015). In the procedure of selection, the solutions that are better ranked and more dispersive are preferred. The new generation of feasible solutions would repeat the procedure of NSGA-II until there is no more improvement or alterations can be seen in the Pareto fronts or the pre-set maximum iterations have reached. In this paper, we make some modifications on the procedure of NSGA-II in order to fit the proposed SSC problem better. The procedure of our proposed NSGA-II algorithm is presented as follow.

3.1 Solution Encoding

The precedence relationships among different activities from different sub-projects can normally be displayed in a form of network. In this section, the precedence network is encoded as three lists: A) An activity pool list for sub-project \(s\) at time \(t\), which can be represented as \(PL_{st}\). The activity pool list includes the available activities that can be selected for scheduling at time \(t\), \(PL_{st}\) is initially formed by including all activities at time \(t\), \(s\), and each activity in the pool can be repeated. As in this paper, time \(t\) is considered as discrete and integral, hereby, the number of same element for a specific activity appears in \(PL_{st}\) is based on its duration. For example, if activity \(j\) of sub-project \(s\) has a duration of \(M\), there will be \(M\) elements that represent activity \(j\) included in the initial pool list; B) A selected activity list for sub-project \(s\) at time \(t\), which can be represented as \(SL_{st}\). The selected activity list is updated by adding the selected activities at time \(t\); C) A predecessor list of activity \(j\) for sub-project \(s\), which can be represented as \(O_{sj}\). For each activity \(j\) from sub-project \(s\), it can only be chosen when the activities included in the list \(O_{sj}\) are all completed. The predecessor list \(O_{sj}\) would be updated after each selection.
by eliminating the completed activities from the list. Hence, activity \( j \) is available for scheduling when \( O_{i,j} = 0 \). A dummy node \( 0 \) is set as the starting point of this list, where \( O_{i,j} = 0 \) means that activity \( j \) can be scheduled as the first activity for sub-project \( i \).

The solution of SSC optimization problem, which in this paper is the schedule of the mega project, can be encoded as a time axis matrix, \( T S = [a_{i,j}] \in \mathbb{R}^{I \times J} \). The time axis matrix has \( I \) rows and \( J \) columns, where each element \( a_{i,j} \) represents an activity from sub-project \( j \) entitled with the series number \( a_{i,j} \) that is conducted at time \( t \). For example, \( a_{i,j} = j \) means that activity \( j \) from sub-project \( i \) is selected for operation at time \( t \). None of the activities would be carried out for sub-project \( j \) at time \( t \) when \( a_{i,j} = 0 \).

3.2 Procedure of NSGA-II

The procedure of NSGA-II is shown in Figure 5 which comprises four main steps.

Step 1. Population Initialization:
In order to generate better offspring, a random population with the size of \( 2N \) is generated at the initial stage. To transfer this initial population into feasible solutions, three criteria that include activity availability, workforce availability and precedence constraint should be checked for each generated chromosome.

Step 2. Fitness Evaluation and Selection:
For each generated solution, the fitness value which refers to the objective values should be calculated. All individuals from initial feasible population are ranked into different dominated fronts based on non-dominated sorting procedure. For each individual \( q \) from this \( 2N \) population, the number of individuals that dominate \( q \) and the set of individuals that \( q \) dominates are calculated. By updating these two entities for every individual, the solutions are classified into different fronts and ranked from better to worse (Bolanos, 2015). The qualities of individuals from a same front is estimated by their crowding distances, where a greater crowding distance gives a better quality. The crowding distance of an individual measures the density of its surrounding solutions, which can be calculated by using the following algorithm.

Algorithm 1 shows the Pseudo code of crowding distance sorting. In the algorithm 1, \( F \) is a Pareto front that consists of \( N \) individuals, while \( F[i]^{i\text{th}} \) represents the \( i\text{th} \) objective value for \( i\text{th} \) individual in this front. \( F^{\text{max}} \) and \( F^{\text{min}} \) stand for the maximum and minimum values for \( i\text{th} \) objective value. Once non-dominated sorting is completed, the tournament selection mechanism would start to be performed. A new parent population with \( N \) individuals is expected to generated through selection procedure from the initial feasible solution with size of \( 2N \). Individuals from different non-dominated fronts are selected based on the rankings of these fronts, where better ranked fronts will be selected before others until \( N \) individuals are all achieved. If the size of last selected front is greater than the number of individuals needed, individuals with better qualities, which in this case is greater crowding distances, will be chosen first.

\[ \text{Algorithm 1 Pseudo Code of Crowding Distance Sorting} \]

\[
\begin{align*}
\text{Step 1. Population Initialization:} & \\
\text{Step 2. Fitness Evaluation and Selection:} & \\
\text{Step 3. Genetic Algorithm Operators:} & \\
\text{Step 4. Feasible Offspring Generation:} & \\
\end{align*}
\]

In this case, a new solution that might not be obtained by crossover is generated for every row in the time axis matrix. For all elements \( q_{i,j}, j = 1, 2, ..., J \) of each sub-project \( i = 1, 2, ..., I \) two adjacent activities \( a_{i,j-1} \) and \( a_{i,j} \) would exchange with a probability of \( \text{Probution} \). In this case, a new solution that might not be obtained by crossover is generated through mutation, and the diversity of solutions is improved consequently.

Step 4. Feasible Offspring Generation:
The solutions produced by crossover and mutation are not necessarily feasible as they might not satisfy all three criteria described above. Therefore, every individual obtained through crossover and mutation need to be checked and modified by applying the procedure of feasible solution generation presented in Step 1, and a feasible offspring population with size \( N \) will be produced. By combining the parent population and the offspring population, we could have a combined population with size \( 2N \). This combined population will stay in the loop of algorithm for evolution until an optimal solution is produced or the termination conditions are reached.
4 Computational Results

In this section, our proposed mathematical model and NSGA-II algorithm are tested on a case study project. The project consists of 3 subprojects, namely A02, A03, A04, and each project comprises 31 activities, and the network for this project is presented in Figure 4. 31 types of scaffolding components are considered and the demand of each type of component for every activity is generated randomly as well as the durations of activities. By implementing our proposed NSGA-II algorithm, the optimal schedule is produced as a time axis matrix and compiled into a timetable as shown in Figure 5. The optimal objective values for total duration, total cost and the variation of workforce utilization are 1791, 6.6000-6.6003, 0.0053-0.0055. The value of cost is the logarithm to base 10 of the actual number. The results of best 30 solutions are shown in Figure 6.
5 Conclusion and Further Research

This paper studies the supply chain optimization problem in the context of scaffolding construction which aims to minimize the total duration and total cost and maximize the utilization of workforce simultaneously. A multi-objective mathematical model is constructed based on the scenario of a large construction project and a modified NSGA-II algorithm is proposed for coping with this problem. A case study partially based on the real life project is conducted for verifying our model and algorithm. In the future research, a more complex case study is expected to be applied and comparisons between our algorithm and other meta-heuristic algorithms will be carried out.

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7 References


The application of advanced property valuation methods in practice: Evidence from Hong Kong and Nigeria

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Abstract:

Property valuation inaccuracy has received so much attention from real estate stakeholders. Studies have shown that the methods adopted could influence the accuracy of property valuation estimates, and also argued that there is a need for valuers to embrace technology in delivering property valuation services. In order to provide a global insight into the level of property valuation modeling in practice, this study is conducted to investigate the application of advanced property valuation methods in practice from the perspective of a developed and developing countries. Valuers practicing in Hong Kong (developed country) and Nigeria (developing country) were sampled via a questionnaire survey on the property valuation methods they adopt in practice. Their response was analysed using frequency distributions in terms of percentiles. A comparison of the findings from both countries was conducted so as to investigate if there are any similarities or differences between valuers practicing in different climates. A low level of awareness and application of the advanced property valuation methods was found in both the developed and developing countries. This indicates that valuers have not embraced the advanced property valuation methods in spite of their wide application and excellent results in theory. The importance of the application of the advanced property valuation methods in achieving a global sustainable property valuation practice cannot be overemphasised. Hence, all the property valuation stakeholders should collectively accord this issue more attention, so as to preserve the global relevance and integrity of the valuers and the property valuation profession.

Keywords:
Advanced valuation methods, developed countries, developing countries, property valuation, valuers.

1 Introduction

Every property valuation report end-user would expect that a valuer presents an accurate and reliable property valuation estimate that could be relied on in making investment decisions. The reliance on an inaccurate property valuation estimate could have a devastating effect on the cash flow or investment of any real estate investor (private, institutional and government, among others). The prevalence of property valuation inaccuracies in the property valuation estimates provided by valuers practicing in a country could have an adverse effect on the economy of that nation. In a broader sense, this could affect the economies of other nations due to globalization and cross-border investments and in turn, could cause a global issue such as the 2007-2008 global financial crisis (GFC) (Jiang et al., 2013).
Property valuation methods have been categorised into two groups namely the traditional and advanced valuation methods (Tao, 2010). The traditional methods are mostly based on the principle of the comparable method in arriving at property valuation estimate, while the advanced valuation methods mimic the thought process of the property market participants in estimating property values (Pagourtzi et al., 2003). The traditional property valuation methods (comparable, income, cost, residual and profit) are mostly adopted in property valuation practice in different part of the world, especially the comparable method (Jenkins, 2000; Kauko et al., 2002). Whereas, the advanced property valuation methods have only been widely adopted by researchers ( Özkan et al., 2007).

The advanced property valuation methods are being widely adopted by researchers to establish their suitability for property valuation (Adhikari and Agrawal, 2013). These methods have produced improved property valuation results (Amri and Tularam, 2012). And a few countries have seen the advanced property valuation methods being adopted for property valuation exercises in practice (Grover, 2016). In Australia, some companies (non-certified valuers) are providing property valuation reports to the public using artificial intelligence (AI) and automated valuation models (AVMs) (Wilkinson et al., 2017). The property valuation practice in some countries has been documented in the literature (Boyd, 1995; Kimmard et al., 2002; Mooya, 2015; Abidoye and Chan, 2016). Scholars have argued that there is a need for a shift from the traditional property valuation approach to advanced property valuation approach in order to improve accuracy, save time, remain relevant in the technology world, among others (Gilbertson and Preston, 2005; Grover, 2016; Wilkinson et al., 2017).

According to Coyle (2015, p. 3) the following complaints are commonly made by property valuation stakeholders - “over-valuation by appraisers was key reason for the housing crisis”, “low appraisals are holding back the housing market”, “appraisals are too high”, “appraisals are too low” and “what good are appraisals if they don’t protect us from market cycles”. All these and many that are hinged on property valuation inaccuracy could be attributed to the adoption of inappropriate property valuation methods in practice (Aluko, 2007). There is a rapid internationalisation of property markets around the world which has resulted in cross-border real estate investments (Gilbertson and Preston, 2005). Property valuation inaccuracy has remained a global issue (Crosby, 2000), hence, there is a need to empirically evaluate and compare the application of advanced property valuation methods in both developed and developing countries. This would provide an insight into the global property valuation in terms of the present and the future direction. This study aims at bridging the gap between property valuation research and practice which is important in achieving a sustainable global professional practice (Hemsley-Brown and Sharp, 2003; Van de Ven and Johnson, 2006). The remaining part of this paper consists of the research methodology, results and discussion and the conclusion and further research.

2 Research Methodology

In order to achieve the aim of this research, two countries that are regarded as developed and developing countries based on their Human Development Index (HDI) were selected and these countries are Hong Kong and Nigeria, respectively. The quantitative research approach was adopted for this study because it would allow the collection of data from a large group of respondents domiciled in different countries (Easterbrook et al., 2008). The SurveyMonkey platform was utilised to design an online questionnaire that was administered to the valuers practicing in both property markets. The respondents of this study are real estate valuers that are registered with the professional bodies regulating the property valuation practice in the case study property markets. The Hong Kong Institution of Surveyors (HKIS) and The Nigerian Institution of Estate Surveyors and Valuers (NIESV) regulate the property valuation practice and professionals in Hong Kong and Nigeria, respectively.

To achieve a basis of comparison, the same set of questions were posed to the respondents in both countries. The questionnaire included questions about the respondents’ demographics, professional experience, the area of specialisation, awareness and adoption of the advanced property valuation methods in practice. In addition, the respondents were requested to indicate if they are knowledgeable about the advanced property valuation methods and how frequently they use them in practice. The advanced property valuation methods include artificial neural network (ANN), hedonic pricing model (HPM), spatial analysis methods, fuzzy logic and autoregressive integrated moving average (ARIMA) (Pagourtzi et al., 2003; Özkan et al., 2007; Tao, 2010). The link to the questionnaire was sent to the emails of the valuers. For Hong Kong, the email addresses of property valuation firms were retrieved from the website of HKIS and the valuers were expected to respond to the survey (Abidoye et al., 2018). While for Nigeria, the email addresses of the valuers were retrieved from the membership directory of NIESV (Abidoye and Chan, 2016). A total of 67 property valuation firms were identified in Hong Kong (via HKIS website) and on the other hand, 150 email addresses of valuers practicing in Lagos, Nigeria, were retrieved (from the NIESV directory).

At the end of the survey periods, 21 valid responses were received from the Hong Kong valuers and 55 were received from the Nigerian valuers (Abidoye and Chan, 2016; Abidoye et al., 2018). This represents a response rate of 31% and 37% for Hong Kong and Nigeria, respectively, which are both above the commonly achievable rate in the built environment research domain (Akintoye and Fitzgerald, 2000). The data collected were analysed using the Statistical Package for the Social Science (SPSS) and the results were supported by the qualitative data. The application of the advanced property valuation methods in practice is an empirical research exercise and as such, descriptive statistics was used to support the empirical analysis. The descriptive statistics used in the study was presented in terms of frequency distribution and cross tabulation. The detailed analysis of the results is presented in the results and discussion.

The internal consistency of the collected data is shown in Table 1. Cronbach’s alpha values which were estimated to test for the internal consistency of the response of the valuers are 0.67 and 0.74 for Hong Kong and Nigeria, respectively. The overall (response from the Hong Kong and Nigerian valuers) consistency is 0.72. These values are above the 0.60 threshold value that connotes a reliable and valid consistent response among the respondents (Nunnally and Bernstein, 1978).

The information about the valuers sampled in this study is presented in Table 2. It shows that about half (48%) of the sampled Hong Kong valuers possess over 20 years of professional experience. On the other hand, most of the Nigerian valuers possess between 6 and 10 years of experience. Overall, most of the valuers (66%) have acquired an industry experience of between 1 and 10 years. This result shows that the Hong Kong valuers are ageing which is similar to what is obtainable in developed countries such as the US and Australia (Coyle, 2015; Wilkinson et al., 2017). This is opposite to what is obtainable in Nigeria (developing country), which it is dominated by young valuers. This could be attributed to the fact that the clients do not have an alternative to property valuation products in developing countries, compared with developed countries where...
there are other options, such as the provision of property valuation estimates to the public by non-certified valuers/firms (Coyle, 2015). As regards the educational qualification of the valuers, a majority of both the Hong Kong and Nigerian valuers have acquired a Master of Science degree and in both countries, none of the valuers possesses a Doctor of Philosophy degree. It may be suggested that valuers are not keen on acquiring research skills by acquiring a doctoral degree at a university. In both countries, about 25% of the respondents specialise in property valuation, while the rest are involved in consultancy services and general practices. Consultancy services and general practices involve real estate agency, property brokerage, property management, real estate investment analysis and so on which are all essential for the property valuation practice (Mooya, 2015). The background of the Hong Kong and Nigerian respondents suggest that the information extracted from the collected data could be relied on.

Table 2. Valuers’ background

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Hong Kong</th>
<th>Nigeria</th>
<th>Hong Kong and Nigeria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of replies</td>
<td>Percentage (%)</td>
<td>No. of replies</td>
</tr>
<tr>
<td>Years of professional experience</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 5 years</td>
<td>5</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>6 – 10 years</td>
<td>3</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>11 – 15 years</td>
<td>3</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>16 – 20 years</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Greater than 20 years</td>
<td>10</td>
<td>48</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>Educational qualification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Associate degree/higher diploma</td>
<td>5</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>Bachelor of Science</td>
<td>8</td>
<td>38</td>
<td>12</td>
</tr>
<tr>
<td>Master of Science</td>
<td>8</td>
<td>38</td>
<td>25</td>
</tr>
<tr>
<td>Doctor of Philosophy</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>100</td>
<td>55</td>
</tr>
<tr>
<td>Real Estate Specialisation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property valuation</td>
<td>5</td>
<td>24</td>
<td>14</td>
</tr>
<tr>
<td>Consultancy/advisory services</td>
<td>11</td>
<td>52</td>
<td>20</td>
</tr>
<tr>
<td>General services</td>
<td>5</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>100</td>
<td>55</td>
</tr>
</tbody>
</table>

3 Findings and Discussion

Based on the valuers’ level of awareness of the advanced property valuation methods, it was revealed that none of the Hong Kong valuers is aware of other advanced property valuation methods, apart from HPM (see Table 3). 14% of the Hong Kong valuers are aware of HPM. In Nigeria, 32% of the valuers are aware of HPM, while only a few are aware of other advanced property valuation methods. Overall, 72% of the valuers are aware of HPM, while 90% of the valuers are not aware of the other advanced property valuation methods. It could be safe to suggest that the valuers in both countries are knowledgeable about the traditional property valuation methods since they are not familiar with the advanced property valuation methods.

It is shown in Table 4 that the advanced property valuation methods are not been adopted by the Hong Kong valuers. All the valuers indicated that they are not being used at all in property valuation exercises. A similar situation is reported by the Nigerian valuers who do not always use any of the advanced property valuation methods in practice. A few Nigerian valuers indicated that they use HPM occasionally in practice. Overall, it is shown that the valuers do not adopt the advanced property valuation methods in practice. The responses received for HPM in terms of its awareness and application could be attributed to its straightforwardness and simplicity in approach (Chau, 2002). The lack of the wide adoption of the advanced property valuation methods could be due to the adoption of the traditional property valuation methods by valuers in different parts of the world (Jenkins, 2000; Kauko, 2002). This could be attributed to the widespread belief of valuers that the traditional property valuation methods are inviolable, and because of their long history and wide adoption, they should be continually adopted in practice (Mooya, 2011).

Table 3. Awareness of the advanced property valuation methods

<table>
<thead>
<tr>
<th>Advanced Valuation Methods</th>
<th>Hong Kong</th>
<th>Nigeria</th>
<th>Hong Kong and Nigeria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artifical neural network</td>
<td>0 (0%)</td>
<td>21 (100%)</td>
<td>4 (7%)</td>
</tr>
<tr>
<td>Autoregressive integrated moving average</td>
<td>0 (0%)</td>
<td>21 (100%)</td>
<td>5 (9%)</td>
</tr>
<tr>
<td>Fuzzy logic system</td>
<td>0 (0%)</td>
<td>21 (100%)</td>
<td>2 (3%)</td>
</tr>
<tr>
<td>Hedonic Pricing Model</td>
<td>3 (14%)</td>
<td>18 (86%)</td>
<td>18 (32%)</td>
</tr>
<tr>
<td>Spatial analysis</td>
<td>0 (0%)</td>
<td>21 (100%)</td>
<td>6 (11%)</td>
</tr>
</tbody>
</table>

According to Coyle (2015), the history of property valuation has evolved from the data rummage era (1920s – 1970s), to the market analysis era (1980s – 1990s), to data discarding era (1990s – 2000s) and finally the data optimisation era (2010s – present). It is inevitable for valuers to position themselves in order to remain relevant in delivering service to their clients and not lose their clients to other allied professions. “When appraisers think about changes to the valuation profession, they needn’t look further than big data and technology to see just how rapidly things evolve and how crucial it is to remain up-to-date on current best practice” (Coyle, 2015, p. 2). The predictive accuracy of the advanced methods has been widely reported in the literature (Abidoye and Chan, 2017), which may suggest an exploration of the advanced property valuation methods in practice so as to achieve a sustainable practice (Wiltshaw, 1995).
The advanced property valuation methods (AI techniques) are not to replace valuers (Coyle, 2015), this is because the valuers still need to inspect the subject property and get more information about the property which the advanced property valuation models does not produce (Grover, 2016). Also, the valuer should possess a good knowledge of the property market where the subject property is located because this could influence the outcome of the advanced property valuation methods (Hager and Lord, 1985). McCluskey et al. (1997) mentioned that some advanced valuation methods such as ANN, expert systems, among others have been adopted in some countries such as Northern Ireland (Valuation and Land Agency), Malaysia (Valuation Division), USA (Assessment Offices) and the HPM has been adopted in Australia (Department of Lands), Sweden (National Tax Board) and Hong Kong (Rating and Valuation Department) and so on. However, they are adopted by government agencies for mass property valuation.

These tools (advanced property valuation methods) are to enhance the services provided to the property valuation end-users, so as to reduce inaccuracy in property valuations which could, in turn, result in a sustainable property valuation practice (Rossini, 1999). It could be suggested that valuers should not continually rely on the traditional property valuation approaches and expect a revolution that is needed in the property valuation practice. There is a need for a change in the approaches adopted and the time for such a change is now. In the future, the property valuation could experience the following: consolidation of valuation firms, alternative valuation products, specialisation and expertise and the principle of change (Coyle, 2015). This change would require the effort of all the property valuation stakeholders – the valuers, the property valuation firms, the educational institutions, the professional bodies in different countries and governments at different levels (Gilbertson and Preston, 2005).

4 Conclusion and Further Research

The transformation being experienced in different sectors of the global economies due to the advent of information technology has warranted the focus on the developments in the global property valuation practice. This study was conducted to investigate and compare the adoption of the advanced property valuation methods in practice by valuers in both developed (Hong Kong) and developing (Nigeria) countries. The valuers’ level of awareness and application of these methods were examined through an online questionnaire survey. The analysis of the data indicates that it is only HPM that is well known by the valuers. None of the Hong Kong valuers is aware of other advanced property valuation methods, but a few Nigerian valuers are aware of them. Overall, over 90% of the valuers are not aware of these advanced property valuation methods. In terms of the application of the advanced property valuation methods, it was revealed that not many of these advanced methods is adopted in practice in Hong Kong. On the other hand, a few Nigerian valuers indicated that they adopt HPM occasionally. It may be safe to suggest that the valuers in both developed and developing countries do not possess the know-how of the advanced property valuation methods. Despite the numerous excellent results of the advanced property valuation methods reported in the literature (explored in both developed and developing countries around the world), the principal participants (valuers) that are to implement this in practice are still comfortable adopting the traditional property valuation methods. This could be because of the perception of the valuers that the AI approaches are a threat to their jobs. This would not be the situation because a valuer is still needed in a property valuation exercise and the advanced property valuation approaches should only be seen as tools to improve the property valuation practice. In order to achieve a sustainable property valuation practice, all the property valuation stakeholders (valuers, governments, professional bodies, educational institutions and so on) in both developed and developing countries should devise strategies to promote the know-how and adoption of advanced property valuation methods amongst the valuers around the globe. There is an urgent need to overhaul the property valuation practice in different parts of the world by developing the information technology and data analysis skills of the valuers. This is because the property valuation report end-users are demanding impeccable services that the current traditional property valuation approaches may not be able to produce. If the needs of those clients are not being met, this peculiar real estate service (property valuation) could be taken over by charlatans or allied professionals as being experienced in some countries now where firms are providing property valuation figures to the public using the advanced property valuation approaches (AI). This study surveyed only one country from each category, so, a different situation may be obtainable in the other countries. However, this exploration provides an insight into what the situation is in the surveyed markets and which could be a decision-making tool for the stakeholders. It is important to note that the willingness of the valuers in different property markets around the world is necessary to see the gap between property valuation theory and practice been bridged. Therefore, further studies would focus on investigating the reasons for the low know-how of the advanced property valuation among valuers, and also the drivers to achieve a sustainable property valuation practice.

5 Acknowledgement

The author acknowledges all the real estate valuers in both countries of study that responded to the survey. This paper has the same methodology with other papers but a totally different scope and objectives. The papers focus on advocating for property valuation automation, in order to improve property valuation accuracy in different parts of the world.

6 References


Tao, C. (2010), 'On the use of analytic network process for modeling housing prices: A Chongqing perspective. (Doctoral dissertation), City University of Hong Kong, Hong Kong.


However, the actual impact of quality deviations (rework) cannot be assessed without having a systems perspective (Rodrigues and Bowers, 1996; Williams et al. 1996; Love et al., 1999). Having a systems perspective, the complex inter-related structure of various factors affecting the quality deviations can be accounted using the cause and effect feedback loops. System dynamics (SD) introduced by Forrester (Forrester, 1961), is best suited to consider these cause and effect feedback loops.

Much of the art of system dynamics modeling is to discover and represent the feedback processes, which along with stock and flow structures, time delays and nonlinearities, determine the dynamics of a system (Sterman, 2000).


In the previous studies, the complex casual structure of all the influencing factors is not accounted. Moreover, the uncertain nature of the influencing factors is not considered. Traditional deterministic system dynamics modeling technique requires deterministic variables. However, the QM process is affected by many factors which have an uncertain and imprecise nature. Due to the imprecise nature of these factors, traditional deterministic system dynamics is not a good choice to simulate the quality defects considering these uncertainties. The effectiveness of system dynamics as a methodology for modeling and simulating construction processes may be significantly increased if it is extended to deal with imprecise influencing factors and their vague inter-dependencies. This research presents a non-deterministic system dynamics approach to quantify the impacts of quality failures which accounts for uncertainties. The factors that affect the quality defects are modeled through a set of cause and effect feedback loops. The imprecise nature of variables affecting the quality failures is also accounted by fuzzy set theory. So that the cost and overruns caused by the quality defects are simulated and quantified using the proposed non- deterministic system dynamics approach.

3 Research methodology

3.1 System dynamics approach

In this research, a SD based approach is presented to account for complex structure of QM process arising from different inter-related components. Figure 1 presents the conceptual diagram of quality management process. The conceptual model has been adopted from the model proposed by Ford and Sterman (1999) which was originally developed for product development projects. However, the model has been expanded to consider all the factors affecting the QM process.

In system dynamics approach, stocks and flows are used to model the flow of work and resources through a project (Ogunlana and Li, 2003). Stocks represent stored quantities and characterize the state of the system and generate the information upon which decisions are based. Flows are the rate of increase or decrease in stocks (Sterman, 2000). Information feedback loops are used to model decisions and project management policies (Ogunlana and Li, 2003).

4 Model application

4.1 Modeling and simulation of quality management process: Proposed SD approach

In this research, a SD based approach is presented to account for complex structure of
the degree to which a member belongs to a set. By considering S as a classic set whose members are xi, usually membership of this set is as follows:

\[ x_i \in S \]

Accordingly, a distinct border between members and nonmembers of the set is defined. In many actual cases, however, these boundaries are not clearly defined. In that cases membership function could be defined as follows:

\[ n_i \notin S \]

According to the non-deterministic system dynamics for quality management, SD modeling has been applied to construction project management domain problems and the literature on its application is sizable. However, almost all of these previous works have been performed deterministically. The project management processes like QM are affected by many factors which have an uncertain and imprecise nature. Due to the imprecise and uncertain nature of these factors, traditional deterministic system dynamics have not the capability to simulate the process considering the existing uncertainties. The effectiveness of system dynamics as a methodology for modeling and simulating construction processes may be significantly increased if it is extended to deal with imprecise variables and their vague inter-dependencies. Fuzzy set theory introduced by Zadeh (1965) is best suited to consider the uncertain nature of these factors.

Conventional sets mainly deal with sets which their membership is defined on a yes/no basis. While in fuzzy set theory, membership is not a precise phenomenon. This type of uncertainty is different from stochastic uncertainty which had been described through probability theory long time ago. Stochastic theory is concerned with uncertainty in likelihood of an event’s occurrence but indistinctness in fuzzy sets theory is in description of characteristics of a phenomenon. This concept has been founded out by Zadeh, as he believed that many systems for modeling reality are not successful due to precise inputs they required. Utilizing this theory in practical problems would make the models more consistent with reality.

Concept of Fuzzy Sets Theory is its membership function which represents numerically

\[ \mu_s(x) = \begin{cases} 1 & x_i \in S \\ 0 & x_i \notin S \end{cases} \]

5 Findings and Discussion

The proposed methodology was implemented in a real project to evaluate its applicability and performance. This project is a concrete bridge structure constructing on a lake. The initial duration and cost of the project was estimated as 10 months and 7 million dollars, respectively. Base case assumes that the entire work is performed correctly. In reality, however, some portion of work may be done incorrectly, and the reworks will occur in the project. Existence of these non-conformances will cause major negative impacts in terms of project delays and project cost overruns.

The consequences of quality failure on the project objectives were quantified employing the proposed non-deterministic system dynamics approach. To simulate the quality failure consequences considering uncertainties in the input variables, the traditional deterministic system dynamics was extended to non-deterministic ones using fuzzy set theory as explained before.

The fuzzy numbers of consequences of quality failures on the project cost and duration performance measures are presented in Fig. 3.
The proposed methodology was employed in a bridge project in order to evaluate its applicability and performance. The negative impacts caused by the quality failures was simulated using the proposed non-deterministic system dynamics. Consequently, the outputs of the system were defined as a fuzzy number. It is believed that the proposed methodology offers a powerful tool to simulate the cost and time impacts of quality failures considering the existing uncertainties.

7 References
Development of AR-based pipeline planning approach for on-site MEP conflict resolution

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Abstract:
MEP conflict resolution is a complicated process due to the multidisciplinary coordinative nature of the MEP engineering. The on-site pipeline inspection and modification are still of vital considering the practical issues contributed by ineffective collision detection, as-built deviations, and low constructability and maintainability. This research aims at developing an on-site pipeline refinement system using Augmented Reality (AR) and path-planning algorithms. The system allows users to compare the existing pipe model with the as-built pipeline, and re-plan the paths of potential conflicted pipes to obtain a conflict-free solution. The system includes planning and interaction modules. The planning module defines five constraints, which are slope, turning, elevation relation and proximity, to consider current MEP design criteria. Also, the constraints are embedded into a grid-based path planning algorithm to search the pipeline design solution with a reasonable computational time. The interaction module is developed base on AR visualisation technology to link the information with the direct delivery to on-site users. The system is implemented on a mobile device using a game engine and conducted performance tests in different sizes of searching grids and priorities of pipes to evaluate the calculation time and planning results. The results show that the system can obtain a set of path solution with approximately 10 seconds for all the pipes complying with the pre-defined MEP design requirements. The system is expected to provide an effective and efficient conflict resolving method to improve the MEP construction process and the future maintenance.

Keywords:
Augmented Reality, Automation, MEP Conflict Resolution, Pipeline Path Planning

1 Introduction
Mechanical, electrical and plumbing (MEP) engineering is one of the most important processes in a building construction and directly affects the construction efficiency, building safety and energy usage (Korman et al., 2000). Given the great importance, it faces a challenge on eliminating conflicts among different MEP systems. Such process is time-consuming and expensive and may not satisfy the construction demand. Although Building Information Modeling (BIM) can help integrate all MEP systems on a collaborative platform, the ineffective collision detection results, as-built deviation, and low constructability and maintainability issues still exist. BIM tools dedicated to resolving the conflicts during the design and modeling phase before construction started.
However, Wang et al. (2016) have reported that 78% of collision detection results are ineffective because they often face clashes of the coordination route and the detection results could be dependent with each other. As-built deviations often occur when workers lay out the pipe routes from the pre-designed 2D drawing or 3D model before the installation process. Because of the complexity of the multidiscipline MEP coordination, the MEP model may no longer fit properly during the installation process when there are deviations between structures and the MEP layout (Wang et al., 2016). Previous research pointed out that during pipeline arrangement, visualisation helps handle the detection and response to collisions between pipes and obstacles. However, constructability and maintainability could not be easily discovered in 2D drawing or 3D model because of the scale difference between real world and model. External MEP maintenance tools are needed to identify the pipeline accessibility before construction phase (Lee et al., 2014).

In consequence, current MEP design, practically the detail MEP arrangement process, is still depending on the decision made by an on-site engineer or technician. Moreover, current systems may not satisfy the functional requirements of MEP design criteria, affecting the construction process afterward and increase the difficulty on maintenance.

The aim of this research is to develop an on-site inspection and modification system using path-planning algorithm and AR technology to resolve the current MEP conflict resolution issues. AR technology is used to connect both real pipes and virtual models to assist the user in inspecting the as-built deviations and the planning results. Besides, the path-planning algorithm is used as a core method to refine the path automatically in consideration of functionality, constructability and maintainability issues of MEP coordination. Two research problems have been derived: (1) Does the computational time during the pipeline planning process using mobile device satisfies the time requirement of the on-site decision-making process? And (2) Does the on-site pipeline planning results comply with the pre-defined design requirements of the current MEP coordination?

A performance test of the proposed system is conducted on a mobile AR device to evaluate the calculation time and the parameters input into the system. The calculation time can provide as a reference for future research to estimate the efficiency on the current device with the algorithm developed. The parameters, such as the setting of the path-searching environment, can also provide future research as a benchmark result regarding the levels of detail and search space resolution.

2 Literature Review
How to design MEP systems effectively is a key topic to increase the work safety, quality and efficiency. Korman et al. (2000) capture the knowledge of MEP design criteria: constructability, operability and maintainability from a research project and implement the knowledge to a computer tool to assist the MEP design process. Researchers have analyzed the influences of algorithms and levels of detail on MEP design (Lee and Kim, 2014). In recently years, several researchers dedicated to refactoring the process through developing frameworks based on the advantage using BIM tools. To deal with MEP clash problems, Wang et al. (2016) developed a practical BIM framework for integrating MEP layouts from preliminary design to construction stage. However, the research article also indicated that 78% of collisions by the automated clash detection functions through present BIM tools were ineffective. The paper, therefore, remarked that the emerging of AR technology would satisfy the goal of enhancing and accelerating the process of verifying such deviations.

With the support of AR technology, which can visualise information intuitively, it can reduce the complexity of discussion information while keeping necessary information during the discussion (Lin et al., 2015). Lin et al. (2015) developed an AR multi-screen
system, which can significantly reduce the discussion time of project data finding by 55% and problem prediction by 66% compared with paper-based method. Recent research also uses AR on the project construction process. It can support the worker related spatial information to increase the quality of buildings or to satisfy special design that is more complicated. However, there are few cases using AR on MEP system deviation modification, which is mainly because of the AR device input interface is not as complete as the general PC, to be used in the field with the detail design process may be tedious. In MEP coordination, it is possible to integrate path-planning algorithm to minimise user input and manipulation, and thus achieve on-site piping modification purposes.

The piping path-planning algorithm is developed to minimise user input and manipulation and speed up the time-consuming pipeline design process to overcome the design problems due to their complexity and concurrency. Researchers conducted evaluations of using the algorithms in design projects, they can significantly reduce the time required for design. Zha and Latombe (1991) describe an approach for designing pipe layouts automatically using cell decomposition method of robot path planning techniques. In addition, Sui and Niu (2016) proposed a modified GA-based approach to solving the complex combinatorial branch-pipe-routing problem, which plays fundamental and critical roles in ship-engine design. Although researchers had been committed to developing the possibility of different algorithms and the automatic design approach had been supported by advance path planning algorithm, in practice, piping engineers still need to manually set and retry the boundary condition and other functional parameters to achieve the project goals.

In summary, it is still critical to deal with the deviation of as-built reality from as-planned MEP design. The trend of AR technology in the field is coming up. However, there is rare research using AR to solve the deviation and clash problems of MEP system, especially for on-site piping modification, because of the limitation of its input interface. With the assistance of path planning algorithms, it is possible to allow the user to design the piping path with a few inputs, which is necessary to make the piping path decision.

3 Research Methodology

This research focuses on developing an on-site pipeline refinement system to achieve the effective on-site MEP conflict resolution. The system contains two modules: planning and interaction. The planning module is as a process which integrates current MEP design knowledge into A* path planning algorithm. The interaction module considered the interaction between user and the system under the AR environment. After the system design, follow-up tests through an implementation on mobile devices and performance tests in the virtual environment are conducted, to identify the feasibility and efficiency of the system.

**MEP System Planning**

The planning module with the embedded algorithm is developed referring to the MEP knowledge bases, which are collected from previous related research (Korman et al., 2000) to make the planning results meet the multidiscipline MEP design criteria. Current design criteria mainly contain three aspects, which are functionality, constructability and maintainability. Given the considerations of the three aspects, a multiple-pipe planning method is proposed to model the multidiscipline MEP coordination and determine path of each systems. It includes a priority sorting process, a constraint embedment process and a MEP A* planner (As shown in Figure 1).

**Priority Sorting:** At the start of planning module, priority sorting calculates the priority of each pipes and obtains an ordered list after sorting them. The constraint and planning steps can then execute the considering pipes by the sorted order. Refer to Korman et al. (2000) whose research summarises the priority of resolving conflicting systems; each attribute can infer to a positive or negative relationship to the resolving order from the feature value. Table 1 shows the priority description of MEP features. The install space, access space, access frequency, length, and cross-section present a positive relationship to the priority, while install sequence presents a negative relationship to the priority. By comparing a certain attribute of each pipes, an ordered list of them is obtained. The first pipe in the list has the highest priority when resolving the conflict, which means that the route of it would not be affected by any other pipes in the list. By contrast, the last pipe in the list has the lowest priority and the smallest space while planning the route of it.
The fourth constraint is relation constraint, which is to guarantee the path of a pipe not being placed above or below another path of pipe. Relation constraint is important for some specific MEP system types. For example, an electric system should add a relation constraint to all other water systems above it to prevent the leaking problem of those water systems to affect the functionality of the electric system. The last constraint is proximity constraint, which is to keep a pipe in a distance away from other pipes. Considering the functionality, proximity constraint can assure the clearance of pipes to other components. For example, there should be a proximity constraint between heating water supply. On the construction aspect, any pipe should add a proximity constraint to keep any other pipes in a distance larger than the install space, in which the worker can easily do the installation of it. Regarding maintenance, the situation is similar on space accessibility.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Constraint</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>System Type</td>
<td>Turning</td>
</tr>
<tr>
<td></td>
<td>Elevation</td>
<td>Relation</td>
</tr>
<tr>
<td></td>
<td>• Firing system have the highest priority</td>
<td>• Firing system have elevation preference to place just above the clear height</td>
</tr>
<tr>
<td></td>
<td>Length</td>
<td>Slope</td>
</tr>
<tr>
<td></td>
<td>• The pipe with longer length has higher priority</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cross Section</td>
<td>Proximity</td>
</tr>
<tr>
<td></td>
<td>• The pipe with larger cross section has higher priority</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Install Space</td>
<td>Proximity</td>
</tr>
<tr>
<td></td>
<td>• The pipe requiring larger install space has higher priority</td>
<td>• There is a cylindrical constraint which adds penalty to other pipes within the cylindrical boundary</td>
</tr>
<tr>
<td></td>
<td>Install Sequence</td>
<td>Elevation</td>
</tr>
<tr>
<td></td>
<td>• The pipe with prior install sequence gets higher priority</td>
<td>• There is a directional constraint which adds penalty to other pipes below</td>
</tr>
<tr>
<td></td>
<td>Access Space</td>
<td>Proximity</td>
</tr>
<tr>
<td></td>
<td>• The pipe requiring larger access space has higher priority</td>
<td>• There is a cylindrical constraint which adds penalty to other pipes within its boundary</td>
</tr>
<tr>
<td></td>
<td>Access Frequency</td>
<td>Elevation</td>
</tr>
<tr>
<td></td>
<td>• The pipe with higher access frequency gets higher priority</td>
<td>• There is a directional constraint which adds penalty to other pipes below</td>
</tr>
</tbody>
</table>

As shown in Figure 1, all constraints will finally be embedded into the A* planner. For the type of slope, turning and elevation, constraints are generated at the start of all the planning process of pipes because the user or the design codes determine all the parameters of these constraints. By contrast, for the type of relation and proximity, constraints cannot be generated before the planning is done. Therefore, after planner determines the path of a pipe, the system generates relation and proximity constraints for it according to parameters pre-determined, such as requirements of install space and access space. Then they will be stored into an accumulated list of constraints and will affect the following pipes during planning process.

** MEP A* Planner:** A modified A* algorithm is proposed as a base of the MEP A* planner to search the shortest path in a short time period. It considers a grid space as the searching base of the A* algorithm. The five constraints, turning, slope, elevation, relation and proximity constraint, will be checked whenever the A* planner explores a neighbor node (grid element) from the current node during the sequential planning process in the grid space. If the neighbor point violates a constraint, the planner will add a penalty value to the traveling cost passed through this neighbor node. Furthermore, the penalty value of each types of constraints are different from each other. Some of the penalty value are relatively higher if the MEP design code have explicit listed the requirement; however, the penalty values of other constraints are lower. For example, the penalty values of slope and elevation constraints are higher than the value of others because the two constraints are from a defined value in the design code. By contrast, the penalty values of relation and proximity constraints are less but still affecting the planning paths to comply with the design requirements. The turning constraint have lowest penalty value in general because it only affects the cost of design. However, for pressurized systems, the turning constraint of them still could have a high penalty value to ensure the pressure of the liquid inside comply with the design requirement.

### 3.2 AR-based Interaction

To deal with the interaction process between the user and the conflict resolution system, an interaction module is designed. It allows the user to do space ranging, model inspection, conflicted pipes selection, constraint setting, and priority setting. To synchronise the position of the user and the camera in the virtual world of the system, it needs to obtain the user position related to a known position through the space ranging. In the space-ranging step, the user must align the device with a known position, which is a tag in the real world. Then the system moves the virtual camera to the position of the user in the virtual world to complete the localisation. Afterward, the system displays the existing BIM model to the user.

The second step is to inspect the existing model to find out if there is any confliction of pipes. In the case, if the BIM model is different from the built pipes, the user needs to update the model through the BIM editor manually or even through the collected data from laser scanning. After determining the conflicted pipes, the user can start setting the input for the planning module through pipes selection, constraint setting, and priority setting. The user can select the conflicted pipes to highlight them and change the constraint setting of each pipe, including whether to add the constraints and their parameters, if the original setting is inappropriate. Then the user can specify which priority sorting way is suitable under the design requirements. Finally, the planning module will calculate the paths of pipes and display the result for the model inspection step. The whole interaction module is a recursive process to allow the user to interact with the system and try out an optimised solution for the conflicted pipes.

### 3.3 Implementation

To achieve the functions of the on-site MEP conflict resolution, the system is implemented using different software and packages, including Unity 3D, Autodesk Revit, Apple ARKit and iOS. As mentioned previously, the first step of using the system is the localisation by the user to grasp the starting point. Figure 2(a) shows the partial building model from Autodesk Revit. After the user chooses the current floor where the user stays, the system displays only the model of the chosen starting point. The user needs to align the virtual camera with the real tags of the specific starting point and confirms it by tapping the localise button. Then the localisation is done and the virtual model is overlapped on the real building elements as Figure 2(b) shown.

The next step is inspection, the user can check the current model and prepare the input information for the planning module, including conflicted pipes, constraint settings, and priority settings. After tapping on the considering or conflicted pipe, Figure 2(c) shows the user interface of the interaction module. The user can overview the information of considering pipe. Afterward, in the interface panel of the system, the user can determine whether to set the detail setting of each constraint. Then, before start re-planning the conflicted pipes, the user can specify which sorting priority to execute in the planning module. The user can either select all concerns of sorting priority by default to obtain complete results as shown in Figure 2(c). Finally, as the resulting model of the yellow
pipe shown in Figure 2(d), the user can see the planning result of each sorting priorities and choose the best one as the final resolution.

![Figure 2. The implementation results of the MEP conflict resolution process](image)

4 Evaluation and Discussion

To validate the performance and feasibility of the system, performance tests are conducted in a room space scenario:

4.1 Test Scenario

The test scenario is a general indoor room space with the size of 13 metres in length, 10 metres in width, and 4 metres in height. There are eight columns with 90 by 90 centimetres cross section and four walls around the room. Also, there are the two columns with 40 by 60 centimetres cross-section. They placed on the long edges and over the room space, and they are the main obstacles in the scene, which would block the path of pipes. Moreover, considering the room for human usage, the clear height is set as 2.8 metres; therefore, the proper space for all pipe paths is 2.8 to 4 metres from the floor. Finally, the planning targets of the scenario are twelve conflicted pipes with different types, which are consisted of six firing pipes in the same system, two electrical pipes, two pressurized water pipes and two gravity-driven water pipes as Figure 3 shown.

Because the sprayers should not place over any other pipes to assure the spraying function, on firing pipes, there are elevation constraints to keep the paths near to clear height and relation constraints that affect any pipes below them. Besides, proximity constraints are applied to keep the clearance, access space and install space. For the two electrical pipes, there are also turning and proximity constraints on them for the design requirement. However, the relation constraints only affect other upward water pipes that are not classified as the electrical system. For the pressurized pipes, most constraints are same as the pressurized pipes, but there are slope constraints to ensure the motion of liquid in pipes.

The scenario is sliced into six different sizes as 0.1, 0.15, 0.2, 0.25 and 0.3 metres as the searching bases of the MEP A* algorithm. Also, there are six different sorting orders of conflicted pipes, which are those under the concerns of the above-mentioned priorities.

4.2 Test Results

The performance test is conducted on iPhone 6s, which has a 64-bit 1.85 GHz ARM-based system-on-chip and 2 GB of LPDDR4 RAM included.

![Figure 3. Test scenario: room space](image)

The results of planning time in the room space are shown in Figure 4. In the group of grid size equal to 0.1 metre, the computational time is rapidly growing comparing with other groups. The average time of the 0.1-metre group is 28 seconds, which means users must wait for nearly 2 minutes and 48 seconds to obtain all six results with different sorting orders. For other groups with grid size less than 0.15 metre, the time to obtain a planning result is less than 7 seconds.

![Figure 4. Planning time under different sizes of grid nodes in room space](image)

The feasibility of results in room space are shown in Table 2. The feasibility is classified as three degrees. First one, the solid circle, is marked if all pipes have found the path and obey all constraints been set. Second one, the hollow circle means all pipes have found the path but some paths violet the constraints. Last one, the dash, means that some pipes cannot found the path, which is the fail result for the resolution. In the result of room space, most results have found paths and obeyed all constraints. However, in some groups sorted by length and access frequency priority, some path points violet the relation constraints. In the group of 0.3-metre grid sorted by access frequency, the result shows that the planner cannot find a path for pressurized pipes.

To evaluate the cost of planning results, total length of pipes along the path is considered. Table 3 shows the total length of pipes of a different group of variant sizes of the grid node and sorting priorities in the room space. The average lengths in the same size are...
disturbed from 138.3 to 142.3 metres, and there is little difference among those with different sizes. Besides, in most of the group sets, the results sorted by the cross section priority are with shortest paths comparing with other groups under the same grid size.

Table 2. Feasibility of planning results of different priorities and grid sizes in room space

<table>
<thead>
<tr>
<th>Grid size (m)</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.25</th>
<th>0.3</th>
<th>0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Cross Section</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Access Space</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Access</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Frequency</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Install Space</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Install Sequence</td>
<td>●</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

- All pipes have path and obey constraints; ○: Some pipes violate constraints; -: Some pipes cannot find path.

Table 3. Total lengths of pipes of different priorities and grid sizes in room space

<table>
<thead>
<tr>
<th>Grid size (m)</th>
<th>0.1</th>
<th>0.15</th>
<th>0.2</th>
<th>0.25</th>
<th>0.3</th>
<th>0.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>140.6</td>
<td>139.65</td>
<td>140.6</td>
<td>137.75</td>
<td>137.1</td>
<td>140.0</td>
</tr>
<tr>
<td>Cross Section</td>
<td>139.6*</td>
<td>137.55*</td>
<td>140.6</td>
<td>136.25*</td>
<td>134.7*</td>
<td>137.9*</td>
</tr>
<tr>
<td>Access Space</td>
<td>144.8</td>
<td>138.15</td>
<td>140.2*</td>
<td>140.75</td>
<td>139.5</td>
<td>144.9</td>
</tr>
<tr>
<td>Access</td>
<td>142.2</td>
<td>140.85</td>
<td>140.6</td>
<td>138.25</td>
<td>-</td>
<td>140.0</td>
</tr>
<tr>
<td>Frequency</td>
<td>142.6</td>
<td>140.85</td>
<td>141.0</td>
<td>139.25</td>
<td>138.9</td>
<td>142.1</td>
</tr>
<tr>
<td>Install</td>
<td>144.0</td>
<td>140.55</td>
<td>141.8</td>
<td>140.75</td>
<td>141.3</td>
<td>143.5</td>
</tr>
<tr>
<td>Average</td>
<td>142.3</td>
<td>139.6</td>
<td>140.8</td>
<td>138.8</td>
<td>138.3</td>
<td>141.4</td>
</tr>
</tbody>
</table>

*: The shortest result in the same grid size

4.3 Discussion

Based on the results of the performance test, the smaller size of grid returns the higher resolution of the result but requires more computational time. It took 28 seconds for obtaining one result per pipe set in the groups with the 0.1-metre grid, which is too long for the case of the on-site decision-making process. On the contrary, the time required for those with the grid size larger than 0.15 are less than 10.05 seconds, which means the user need to wait less than one minute to obtain the six results of different sorting priorities. In the 0.25, 0.3 and 0.35-metre groups, there are some pipes, particularly yellow pressurize pipes, violate the proximity or the relation constraints with other ones. Because the space is sliced too roughly, there is no space for the pressurized pipe to pass over from top of the firing pipe. This could affect the function of the firing sprayer, but consequently, reduce the total length of pipeline consumption. Similarly, the reasons of the planner cannot find the path for some groups are the pipeline-blocking situations. These situations happen when the size of the searching grid is too large so that the paths of other pipes block all neighor nodes to the target positions. It is also observed that the groups sorted by cross section-first priority return short-length-usage results in all grid sizes. The results are mostly feasible and obey all constraints. This may becaus the cross section of a pipe would directly affect the space usage. Therefore, the authors suggest future users considering the cross section-first to sort the pipes in the planning process.

Implications can be given through the test results: (1) Given that there are few on-site AR-based MEP systems due to a lack of complete interfaces and appropriate manual planning mechanisms, the proposed pipeline path-planning approach shows the feasibility and efficiency to support the current practice in this manner. Furthermore, (2) the integration of MEP design knowledge with on-site MEP coordination is feasible, as long as proper arrangements of pipe priority and search resolution are made. It could enhance the communications between field supervisors and sub-contractors at site for better decisions at sites.

5 Conclusion and Further Research

In this research, a MEP conflict resolution approach is developed to achieve the need for on-site pipeline inspection and modification. Previous research is referenced to divide the MEP knowledge into three categories: functionlity, constructability and maintainability, and accordingly develop a process to plan the path of multiple pipes. The process first sorts the considering pipes by different attributes related to MEP design requirement. Afterward, each pipe delivers the design requirement into a MEP A* planner, which is the planner based on A* algorithm to deal with multiple paths of pipes. This is done by the five categories of constraints defined to consider the special needs of each pipe. On the other hand, the research team focused on the purpose of on-site information interaction with the user and designed the user interfaces in AR-enhanced environment. The final system is built on a mobile application using Unity 3D and ARKit package. To evaluate the performance and the planning results of the system, a virtual scenario is designed with a series of testing on different sorting priorities and sizes of the grid. The result shows that the groups in 0.15 and 0.2-metres-grid-size both use little time, within 7 seconds, to get the reasonable sets of pipe paths. This result, given the designed scenario, indicates that the system is an effective and efficient solution for on-site MEP conflict resolution process considering the constructability and maintainability issues.

This research has the limitation of the non-optimisation solution of current planning process. Currently the approach only allows user to obtain path solution from single priority sorting to achieve the sequential path planning process for each pipeline. Therefore, future research can focus on multiple sorting priorities method and determine the weights of the multiple options. Furthermore, the future research can also dedicate to the balance of the grid size and the searching range using advance path-planning algorithms and find the optimised solution considering all sorting possibility.

6 References


A technique for accurately predicting the impact size of uncertainty events on construction time

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Abstract:
This study examines the use of Stepwise Regression Analysis (SRA) and Adaptive Neuro-Fuzzy Inference System (ANFIS) in the prediction of the impact size of uncertainty events on construction time and whether one of the techniques is more accurate than the other. The rationale for the study stems from the availability of several techniques such as regression analysis and machine learning for developing predictive models of relationships of various variables in the construction industry. However, there has been limited research undertaken to compare the accuracy of the available techniques. The success or failure of prediction depends on the reliability of the prediction method. In this study, the predicted impact size of 76 uncertain events on the construction time of highway projects using Stepwise Regression Analysis (SRA) as a classical statistical method and Adaptive Neuro-Fuzzy Inference System (ANFIS) as an intelligent method were compared to delineate the ability and accuracy of the two prediction techniques. The comparison of calculated R-Squared and four error tests for SRA and ANFIS show that the constructed ANFIS model has a higher performance than the SRA method in both fitness and reliability of the prediction model. Also, the performance comparison showed that ANFIS is a good tool for predicting the impact of uncertainty events on construction project time. Based on these findings, the study concludes that the use of intelligent methods such as ANFIS will minimise the potential inconsistency of correlations in construction time prediction.

Keywords:
ANFIS, Construction Time, Performance, Predictability, SRA.

1 Introduction

Providing accurate estimates of time on construction projects is a difficult task because construction projects are subject to risks and uncertainties, especially in the planning phase of the project when insufficient data and information about the project is available (Ökmen & Öztas, 2010). Typically, in the estimation of construction project resources, several variables are not known since uncertainties populate construction projects. According to El Khalek, Azz, and Kame (2016) various uncertainties are existing in construction projects that affect construction performance differently. A project is regarded as successful if it is completed on time, within budget and to the level of quality standards specified during the planning stage (Chan & Chan, 2004). The timely completion of a construction project is one of the most important objectives of the construction manager because delay in the completion of projects tends to incur additional costs (Wysocki, 2011). Accurate estimation of project time is crucial to ensure the successful completion of a construction project (Moghayedi, 2016).

Estimating construction time at the early stage of project development represents a prediction provided by the cost engineer based on available information and data. Time estimating is defined as that area of construction practice where the cost engineers experience and judgment are utilised in the application of scientific principles and techniques to the problem of predicting and controlling time of projects (Ng & Zhang, 2008). The ability to accurately predict the impact size of uncertainty events on construction time has always been one of the most critical challenges of cost engineers (Antunes & Gonzalez, 2015). This advantage enables the cost engineers to estimate the construction time with higher performance. However, the success or failure of prediction depends on the credibility of the prediction method. Classical statistical methods such as regression analysis are quite common in forecasting different variables in construction management. Regression analysis methods are relatively easy to implement and the main advantage of these methods are that the relationship between the input variables and output variables is easy to comprehend.

Stepwise Regression Analysis (SRA) is an extension of Multiple Regression Analysis. The SRA model is a mathematical model used in estimating the relationship between a dependent variable and independent variables with a strong mathematical background. SRA models have been used extensively in different areas of construction management. For instance, assessing the critical factors affecting cost performance of public construction projects (Sinesilassie, Tabish, & Jha, 2017); modelling the construction risk ratings and estimating contingencies in highway projects (Diab, Varma, & Panthi, 2017); identifying the success factors for public, private partnership projects (Yun, Jung, Han, & Park, 2015); evaluating project risks (Ebrat & Ghodsi, 2014); evaluating the risk factors leading to cost overrun in highway construction projects (Creedy, Skitmore, & Wong, 2010); analysing the risk perception of build–operate–transfer road project participants (Thomas, Kalidindi, & Ananthanarayanan, 2003); developing models to forecast the actual construction cost and time (Skitmore & Ng, 2003); and designing a multivariate analysis to build project success factors (Chan, Ho, & Tam, 2001).

On the other hand, hybrid intelligence machine learning methods based on Fuzzy Inference System (FIS) is used in modelling the qualitative aspects without employing precise quantitative analyses, it provides standard practical methods for transformation into rule based as well as effective methods for turning Membership Functions (MF) for better performance index (Chai, Jia, & Zhong, 2009). The Adaptive Neuro-Fuzzy Inference System (ANFIS) combines the strengths of Artificial Neural Network (ANN) with Fuzzy Inference Systems (FIS) to create an efficient method for analysing the complex problems. ANFIS has the capability to handle nonlinearity, uncertainty, and complex problems which are involved in predicting the impact size of uncertainty events on construction time (Jin, 2010).

ANFIS has been used in various fields of engineering. For instance, Ugar (2017) has developed ANFIS to estimate the costs of the residential building. While Fragiadakis, Tsoukalas, and Papazoglou (2014) assessed the occupational risk in the shipbuilding industry; Ebrat and Ghodsi (2014) applied ANFIS to evaluate the risk in construction projects; Li, Su, and Chu (2011) forecasted building energy consumption using hybrid ANFIS; Güneri, Ertay, and YüCel (2011) used ANFIS to overcome supplier selection problem in construction projects; Shahhosseini and Sebt (2011) used ANFIS to establish a fuzzy adaptive decision-making model for selection and assignment of human resources to construction projects based on competency; and Wang and Elhag (2008) developed an ANFIS based risk assessment model for bridge maintenance projects.
However, there are limited researches undertaken using ANFIS in the field of construction management and limited studies have compared the accuracy of SRA to ANFIS as a technique for predicting the impact size of uncertainty events on construction time. Therefore, this study examines the predicted impact size of uncertainty events on the construction time of highway projects using Stepwise Regression Analysis (SRA) as a classical statistical method and Adaptive Neuro-Fuzzy Inference System (ANFIS) as an intelligence method and thereafter compared the accuracy of the two prediction techniques.

2 Uncertainty Events on Highway Projects

Uncertainty means an unknown phenomenon (Norton, Brown, & Mysiak, 2003) that is associated to the location and is project specific and has no root causes that can be generalised (Ramanathan, Narayanan, & Idrus, 2012). Therefore, there is an obvious need to effectively anticipate, identify and classify the uncertainty events on different locations and projects to assess their influence on the objectives of construction projects. Moghayedi and Windapo (2018) identified 76 uncertainty events as affecting the construction time of South African highway projects under seven major groups namely Economical, Environmental, Financial, Legal, Political, Social and Technical as illustrated in Table 1.

Table 1: Uncertainty events on highway construction projects distributed according to causative factors

<table>
<thead>
<tr>
<th>Uncertainty factor</th>
<th>Uncertainty event</th>
<th>Probability of Occurrence</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political</td>
<td>Political situation (PL1)</td>
<td>Almost Certain (.9)</td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td></td>
<td>Enrolment problems (PL2)</td>
<td>Likely (.7)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Transportation delay (PL3)</td>
<td>Possible (.5)</td>
<td>Moderate (5)</td>
</tr>
<tr>
<td></td>
<td>Cultural heritage issue (SO1)</td>
<td>Unlikely (.3)</td>
<td>Major (7)</td>
</tr>
<tr>
<td></td>
<td>Personal conflicts among labour (SO2)</td>
<td>Insignificant (1)</td>
<td>Catastrophic (9)</td>
</tr>
<tr>
<td>Social</td>
<td>Social and cultural impacts (SO3)</td>
<td>Moderate (.4)</td>
<td>High (4)</td>
</tr>
<tr>
<td></td>
<td>Rehabilitation of affected people (SO4)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td>Financial</td>
<td>High cost of materials and/or equipment (LE3)</td>
<td>High (.4)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>High tender price (FI5)</td>
<td>Extreme (.5)</td>
<td>Moderate (5)</td>
</tr>
<tr>
<td></td>
<td>Tax and/or legal fees (FI1)</td>
<td>Moderate (.4)</td>
<td>High (4)</td>
</tr>
<tr>
<td></td>
<td>Specification change (TG9)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Terrain (or topographical site) (EN4)</td>
<td>Moderate (.4)</td>
<td>High (4)</td>
</tr>
<tr>
<td></td>
<td>Weather (EN1)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Insufficient planning and scheduling (TG10)</td>
<td>High (.4)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Delay in material supply (TM2)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Unreliable material supplier (TM6)</td>
<td>High (.4)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Fluctuation of prices of materials and/or equipment (EC5)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Monopoly of equipment (EC1)</td>
<td>High (.4)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Fluctuation in the foreign exchange rate (EC4)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Ineffective delay penalties (LE7)</td>
<td>Almost Certain (.9)</td>
<td>Catastrophic (9)</td>
</tr>
<tr>
<td></td>
<td>Right of way acquisition (LE1)</td>
<td>Likely (.7)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Incomplete drawings, specifications (TCS3)</td>
<td>Possible (.5)</td>
<td>Moderate (5)</td>
</tr>
<tr>
<td></td>
<td>Inadequate planning and scheduling (TG10)</td>
<td>Unlikely (.3)</td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td></td>
<td>Incompetent contractor/subcontractor (TCR7)</td>
<td>Extreme (.5)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Inadequate labour productivity (TL1)</td>
<td>Likely (.7)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Insufficient planning and scheduling (TG10)</td>
<td>Usually Certain (.6)</td>
<td>Catastrophic (9)</td>
</tr>
<tr>
<td></td>
<td>Ineffective delay penalties (LE7)</td>
<td>Almost Certain (.9)</td>
<td>Catastrophic (9)</td>
</tr>
<tr>
<td></td>
<td>High cost of materials and/or equipment (LE3)</td>
<td>High (.4)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Deficient documentation (LE2)</td>
<td>Likely (.7)</td>
<td>Minor (3)</td>
</tr>
<tr>
<td></td>
<td>Poor communication between construction parties (TCS1)</td>
<td>Possible (.5)</td>
<td>Moderate (5)</td>
</tr>
<tr>
<td></td>
<td>Poor financial control (FC1)</td>
<td>Unlikely (.3)</td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td></td>
<td>Size of contract (TG1)</td>
<td>Almost Certain (.9)</td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td></td>
<td>Unlikely (.3)</td>
<td>Insignificant (1)</td>
<td>Insignificant (1)</td>
</tr>
<tr>
<td></td>
<td>Possible (.5)</td>
<td>Moderate (5)</td>
<td>Moderate (5)</td>
</tr>
<tr>
<td></td>
<td>Likely (.7)</td>
<td>High (4)</td>
<td>Extreme (5)</td>
</tr>
<tr>
<td></td>
<td>Almost Certain (.9)</td>
<td>High (4)</td>
<td>Extreme (5)</td>
</tr>
</tbody>
</table>

The 76 uncertainty events identified by Moghayedi and Windapo (2018) was used in the current study to evaluate the performance of proposed techniques for predicting the uncertainty events.

3 Methodology

To model the impact of uncertainty events on construction time and predict the impact size, the probability of occurrence and severity of the event was obtained from 32 project managers with a minimum of 20 years of work experience in South African highway construction projects recommended by The South African National Roads Agency SOC Ltd (SANRAL) using the five-point linguistic Likert scale questionnaires. The hierarchy structure of the model developed for predicting the impact size of uncertainty events consists of four main steps; determination of uncertainty event attributes, data collection, developing the predicting models, comparison and recommendation. The process begins with a determination of criteria for uncertainty assessment. The magnitude influence of uncertainty can be assessed by two parameters, probability of occurrence and severity (ISO, 2009; Rose, 2013). To model, the impact of uncertainty events on construction time, the ISO 31000 (International Standard Organization) impact matrix was used (ISO, 2009). Figure 1 shows the probability of occurrence and severity as two input variables relevant impact size as output.

![Figure 1: Probability of Occurrence of the Event and Severity](image-url)
Adaptive Neuro-Fuzzy Inference System (ANFIS) refers to combinations of Artificial Neural Networks (ANN) and Fuzzy Inference System (FIS). Fuzzy modelling and ANN have been recognised as powerful tools that can facilitate the effective development of models and integrate information. These two tools were combined to achieve readability and learning ability at the same time (Jantzen, 1998). ANFIS, trained to develop fuzzy rules and determine Membership Functions (MF) for input and output variables of the system (Huang, Negnevitsky, & Nguyen, 2002) is an intelligent system which is able to estimate the variables and fuzzy rules intelligently and does not require a systematic method for design of fuzzy systems. ANFIS has the capability to handle uncertainty, nonlinearity, and complex problems which are involved in most construction management decision-making processes (Jin, 2010). Also, neural network fuzzy systems interpret the human knowledge and deduce it into a mathematical model (Negnevitsky, 2005). The Neuro-Fuzzy has two major categories namely: linguistic fuzzy modelling which is focused on interpretability (Mamdani), and precise fuzzy modelling which is focused on accuracy (Takagi-Sugeno) (Lughofer, 2011).

### 4 Stepwise Regression Analysis (SRA)

The impact size of uncertainty event as the dependent variable is a function of two independent variables namely probability of occurrence and severity of relative uncertainty (ISO, 2009) as shown in Equation 1.

\[
\text{Uncertainty Impact}_i = a_p + b_s + r_i \quad (\text{Equation 1})
\]

where \(r_i\) is a constant value, \(a\) and \(b\) represent regression coefficient of independent variables.

The linear regression analysis was used to generate correlations coefficients of the two independent variables (probability of occurrence and severity of uncertainty) by using the stepwise regression in the MATLAB. A stepwise technique was selected due to the low correlation between the independent variables and dependent variable as presented in Table 2.

### Table 2. Correlation matrix among input and output variables

<table>
<thead>
<tr>
<th>Probability</th>
<th>Severity</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Severity</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Impact</td>
<td>0.685061</td>
<td>0.685061</td>
</tr>
</tbody>
</table>

The general SRA model for predicting the impact size of uncertainty events has been developed based on the matrix impact in Figure 1. The SRA model test details are presented in Table 3.

### Table 3. Regression test details

<table>
<thead>
<tr>
<th>Multiple R</th>
<th>RMSE</th>
<th>MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.968822</td>
<td>0.245</td>
<td>0.248</td>
</tr>
</tbody>
</table>

The regression test revealed the correlation coefficient value of the model is close to 1 which verifies the close fitness of the estimated output model with real data. Also, the low value of P-value (<0.05) indicates the statistically significant relation of each independent variable to the dependent variable of the model. The developed Stepwise Regression Analysis model for general uncertainty impact size is outlined mathematically in Equation 2.

\[
\text{Uncertainty Impact} = 0.18 + 2.9 \times p + 0.29 \times s \quad (\text{Equation 2})
\]

The similar process was repeated to generate the SRA uncertainty impact models for each event. To predict the impact size of uncertainty the optimum values of probability of occurrence and severity of event are identified using sensitivity analysis and incorporated into SRA models. The impact of uncertainty events on the construction time of highway projects was predicted and ranked. To evaluate the performance of SRA models on predicting the impact size of uncertainty events the Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and the correlation coefficient value of developed models were calculated and the results for top 20 events are presented in Table 4.

### Table 4: SRA models predicted impact size and performance evaluation for top 20 events

<table>
<thead>
<tr>
<th>Event</th>
<th>Probability of occurrence of event</th>
<th>Model Impact</th>
<th>RMSE</th>
<th>MAPE</th>
<th>R Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>TG11</td>
<td>0.84375</td>
<td>8.5625</td>
<td>0.19</td>
<td>0.0278</td>
<td>0.441</td>
</tr>
<tr>
<td>TG56</td>
<td>0.79235</td>
<td>9.2056</td>
<td>0.24</td>
<td>0.0424</td>
<td>0.70</td>
</tr>
<tr>
<td>EL11</td>
<td>0.8125</td>
<td>11.3696</td>
<td>0.26</td>
<td>0.0533</td>
<td>0.944</td>
</tr>
<tr>
<td>SO3</td>
<td>0.75</td>
<td>6.0025</td>
<td>0.36</td>
<td>0.0651</td>
<td>0.725</td>
</tr>
<tr>
<td>EN3</td>
<td>0.59075</td>
<td>4.184651</td>
<td>0.25</td>
<td>0.0516</td>
<td>0.75</td>
</tr>
<tr>
<td>EN2</td>
<td>0.66855</td>
<td>5.6525</td>
<td>0.28</td>
<td>0.0587</td>
<td>0.703</td>
</tr>
<tr>
<td>SC2</td>
<td>0.6325</td>
<td>4.2525</td>
<td>0.26</td>
<td>0.0553</td>
<td>0.701</td>
</tr>
<tr>
<td>SC36</td>
<td>0.41255</td>
<td>2.1252</td>
<td>0.24</td>
<td>0.0571</td>
<td>0.658</td>
</tr>
<tr>
<td>FI6</td>
<td>0.70655</td>
<td>4.1875</td>
<td>0.25</td>
<td>0.0562</td>
<td>0.703</td>
</tr>
<tr>
<td>TC9</td>
<td>0.5525</td>
<td>2.2856</td>
<td>0.25</td>
<td>0.0626</td>
<td>0.661</td>
</tr>
<tr>
<td>TC55</td>
<td>0.64255</td>
<td>3.3185</td>
<td>0.24</td>
<td>0.0632</td>
<td>0.60</td>
</tr>
<tr>
<td>TCS4</td>
<td>0.64255</td>
<td>3.3185</td>
<td>0.24</td>
<td>0.0632</td>
<td>0.60</td>
</tr>
<tr>
<td>SO3</td>
<td>0.55</td>
<td>2.1252</td>
<td>0.25</td>
<td>0.0562</td>
<td>0.703</td>
</tr>
</tbody>
</table>

The small error scores of RMSE (e<0.3) and MAPE (e<0.1) proved the reliability of SRA developed models (Veerasamy, et al., 2011). However, the fitness of the predicted
values to real data varies from 0.441 to 0.94. Which only one model has good fitness (0.9>r>0.8), nine models have acceptable fitness (0.8>r>0.7), and the other ten models have a low fitness (r<0.7) to the real data (Moore & Kirkland, 2007; Seggiani, 1999).

5 Adaptive Neuro-Fuzzy Inference System (ANFIS)

In this study, a first-order Takagi-Sugeno fuzzy inference system is employed to accurately assess the impact size of uncertainty events in construction time of highway projects. In this inference system, the output of each rule is a linear combination of two input variables added by a linear term of “AND” logic. The final output is the weighted average of each rule’s output (Buragohain & Mahanta, 2008). Figure 2 illustrates the Takagi-Sugeno ANFIS structure which was developed for this study. To model this ANFIS following 25 fuzzy rules “IF-Then” are considered.

\[ \text{If } (P \text{ is } p) \text{ AND } (S \text{ is } s) \text{ then } f_i = a_ip + b_is + r_i, \quad i=1,2,3,4,5 \]  

(Equation 3)

Where \( P \) and \( S \) are numerical inputs while \( p \) and \( s \) are numerical variables. Membership functions identify these variables. Also, \( a_i, b_i \) and \( r_i \) are parameters that determine the relation between input and output.

ANFIS is modelled in the MATLAB to predict the impact size of uncertainty events. Eighty percent (80%) of the data collected from the research participants was used for training of the FIS, while the twenty percent (20%) was used for checking and testing the neural network which set the system parameters. To evaluate the ANFIS performance, the RMSE, MAPE and R-Square value of predicted impact size of uncertainty events are calculated and the result for the selected 20 events are presented in Table 5.

6 Discussion of Findings

This study employs SRA and ANFIS in modelling the uncertainty events in the construction time of highway projects and thereafter compares the prediction performance of each technique. The success or failure of prediction depends on the credibility and performance of the prediction technique. The comparison of calculated R-Squared value from SRA technique (Table 4) and ANFIS technique (Table 5) revealed that the intelligent machine learning method significantly closed the R-Squared of ANFIS 1, which means the predicted impact size of uncertainty events by ANFIS has a higher fitness to the real data. For instance, the fitness of predicted impact size of event TG11 is improved from very low fitness (0.441) to excellent fitness (0.999999999999976) similarly for all the events.

Also, intelligent machine learning technique improved the reliability of prediction by reducing both error indicator scores. Table 5 shows the two minimal error values of ANFIS on predicted impact size (very close to 0). For Instance, the RMSE score is decreased from 0.19 to 7.64E-07 similarly the MAPE score is reduced from 0.0278 to 9.70E-08. Therefore, the minimal error indicators values and the extreme closeness of the R-Square to 1 for ANFIS technique manifested the higher credibility and accuracy of intelligent machine learning methods in predicting the impact size of uncertainty events when compared to the classical statistical method. Furthermore, the comparison of the predicted impact size of the uncertainty events from SRA and ANFIS techniques revealed that the SRA technique generally underestimated (64 out of 76) of impact size of events by an average of -2.2%.

The minimal error scores of RMSE (e<0.3) and MAPE (e<0.1) proved the high reliability of ANFIS models (Veerasmey et al., 2011). Furthermore, the extreme closeness of R-Square values to 1 verified the excellent fitness (e<0.9) of predicted impact sizes of all 20 models to the real data (Moore & Kirkland, 2007; Seggiani, 1999).

7 Conclusions

This study examines the capabilities and credibility of SRA as a classical statistical method and ANFIS as an intelligent machine learning method for predicting the
impact size of uncertainty events on construction time of projects. The results show that intelligent machine learning method (ANFIS) produces higher performance than the classical mathematical method (SRA) in both fitness and reliability of the prediction model. Also, the research results suggest that intelligence machine learning methods such as ANFIS could be used as a superior technique for predicting the impact of uncertainty in construction projects mainly when the input data are ambiguous or subject to relatively high importance.

The hybrid intelligent learning ability of Fuzzy Inference System (FIS) empower the ANFIS in learning, modelling and analysing the qualitative aspects of data such as human knowledge. The strength of the hybrid intelligent learning methodology provides simple and efficient approach over other conventional methods of predicting such as classical statistical techniques including Regression Analysis. Besides accurate prediction and evaluation of uncertainty impacts, the ANFIS also reduce the potential inconsistency of correlations.

The study advances that the use of ANFIS technique could be extended to the management of uncertainties in various sectors of the construction industry. Also that managing the uncertainties on projects could be executed more systematically using the advantages of the designed FIS and higher performance of predicted size by ANFIS. The use of a similar approach in evaluating the performance of intelligent machine learning methods as a predictor of various variables in the construction industry such as project complexity and project performance is recommended as the focus of further studies.

## 8 Acknowledgements

The financial assistance of the National Research Foundation (NRF) towards this research is hereby acknowledged. The opinions expressed, and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the NRF.

## 9 References


Abstract:
Digital technologies (DTs) have the capability to change the ways supply chains operate, making them more connected and efficient, from supply points to the construction sites. However, the problem tends to lie with implementation of the technologies. This paper is an overview of DTs to enable the digitization of construction supply chain (CSC) practices. The study identified twenty-two DTs and categorized their applications to five aspects of the supply chain as a basis of analysis: (1) supply chain integration and collaboration, (2) digital procurement and warehouse management, (3) communication and information flow, (4) visual monitoring and logistics visibility in real time, and (5) material and inventory management. This study is a literature-based theoretical exploration, and a preliminary stage of an ongoing doctoral research aimed at signifying digitization as a function of productivity performance in the New Zealand Building Industry. Insights gained from the foregoing findings will inform practitioners contemplating digitization of the sector’s supply chains to improve productivity and cost efficiency.

Keywords:
Cost efficiency, digital technologies, digitization, productivity, supply chain

1 Introduction
The construction industry frequently struggles with low productivity, cost overruns, project delays, and poor safety management (Vogl & Wahab, 2015). In face of these challenges, numerous studies identified supply chain management as a viable solution to these issues (Harty, 2008). However, the supply chain has multiple functional silos, in particular lack of integration, coordination, and scheduling issues (Abedi, Fathi, Mirasa, & Rawai, 2016). Digital technologies (DTs) minimize these bottlenecks and enable firms to adjust their supply chains in real time and build resilience to deal with uncertainties (Kumararawmy, Ng, Ugwu, Palaneeswaran, & Rahman, 2004). As DTs are provided by multiple vendors, users may not be familiar with the technical and application domain (Hinkka & Tätilä, 2013). This provides a unique platform to comprehensively review the applications of DTs on CSC.

In New Zealand (NZ), CSC management (CSCM) capability is perceived as a principal enabler to meet the housing demand quicker and at lower cost (Ying et al., 2015). Internationally, a number of significant studies overviewed DTs application for construction procurement (Ibem & Laryea, 2014), construction e-commerce (Zou & Seo, 2006), supply chain proximity (Dallasega et al., 2018), mobile internet technologies for CSC (Shi, Ding, Zuo, & Zillante, 2016), and Internet of Things (IoT) and supply chain management (Doya et al., 2017). This review paper coherently extends recent literature review on DT applications to digitize CSC. This study identifies available DTs to support
CSC practices, with a view to investigating the theoretical role of DTs in improving supply chain efficiency. To researchers’ best knowledge, there is no recent documentary evidence of an investigation into CSC digitization for NZ construction. In other words, how the potential of digitization operates across the CSC practices is yet to be studied. This study therefore intends to fill the gap, hence the need for the study.

2 Literature Review

DTs are referred to advanced information and communication technologies (ICT) that offer novel capabilities of automating work, facilitating communication, and information (Hamelink, 1997). In the context of Industry 4.0, organisations are expected to become digitized in their operations to boost productivity (Schrauf & Bertram, 2016). This mandates the traditional supply chains to evolve towards an integrated, efficient digital supply chain network. For the purpose of this study, DTs are referred to wide range of standalone, integrated, web-based, and internet enabled technologies and tools used to support basic CSC practices. CSCM has its roots in the manufacturing industry, with principles of lean management, just in time (JIT), and total quality management (Vrijhoef & Koskela, 2000). However, fundamental differences between the two industries, in particular temporary projects and transient locations, post inevitable challenges to directly apply inter-industrial supply chain practices (Young et al., 2011).

Digitizing the supply chain is expected to bring annual gains of 4.1 percent and 2.9 percent in efficiency and revenue respectively (Schrauf & Bertram, 2016). This is a powerful motivator to implement DTs across the New Zealand construction industry (Fuemana et al., 2013). NZ’s geographical isolation make supply chain efforts vulnerable, imposing challenges in quick movement of materials and resources (Bosnet, Corner, Wisner, & Tan, 2003). Moreover, lack of culture to bring about change hinders supply chain efforts. Although this insight was gained from manufacturing industries but were later extended into the construction industry. Ying et al. (2015) investigated supply chain practices in NZ construction and found that the flow of materials and logistics are crucial CSCM links. As noted by the New Zealand Productivity Commission (2012), “without good management and procurement practices, this fragmentation in the supply chain can generate inefficiencies, time delays and re-work, which drive up cost and reduce quality”. While the traditional supply chain operates under the Supply Chain Operations Reference (SCOR) model: plan, source, make, deliver, and return (Cheng et al., 2010), a number of authors explained the construction supply chain framework, illustrated in figure 2. Although several authors examined technology applications to digitally enable CSC flexibility, visibility, and integration, there is no reference of a ‘digital construction supply chain’ in literature. Hence for the context of this study, a digital supply chain is referred to an evolution of the traditional supply chain practices leveraged by advanced ICT.

In relation to major, contrasting industrial contexts of aerospace and manufacturing, the construction supply chain is much less established (Schober et al., 2016). On the other hand, a number of international studies indicate a growing utilization of DTs in CSC over the last two decades (Guo, Scheepbouwer, Yiu, & Gonzalez, 2017), focus of this study. Moving forward, this research intends to provide context, implications, and strategies for supporting the NZ building industry, in particular the housing sector, with new technologies. This paper address DT application through the lens of CSC practices, based on international review. It also provides a useful point of reference to academics and industry practitioners contemplating similar projects. However, factors affecting its successful implementation is outside the scope of this study.

3 Research Methodology

This study addresses research objectives from evidence-based literature adopted from Ibem & Laryea (2014). The approach brings together evidence from multiple studies on the subject to inform practice. Using Scopus as the main source of literature, a literature review is conducted between 1998 and 2018. Authors chose this timeframe because DT applications started to gain traction from practitioners over the last two decades (Valero et al., 2015). The research method consists of three main phases, as shown in figure 1. In phase 1, articles were searched by rearranging key phrases under ‘TITLE-ABS-KEY’. Search key words include: ‘digital technology AND construction supply chain’; ‘industry 4.0 AND construction supply chain’; ‘technology AND construction supply chain AND efficiency’; ‘information and communication technology AND construction supply chain’. In phase 2, only top ranked, peer reviewed, and English journals were selected. All conference proceedings, trade publications, book series, books, forum, seminar report, briefing comments, and editorials were excluded. Next the papers were examined visually and articles that did not focus on DT applications to CSC were discarded. Because CSC digitization is a relatively new concept, authors adopted snowballing technique and added 11 relevant articles manually at phase 3. Snowballing technique was successfully used in similar survey studies by Shi et al. (2016), to back up the possible omission of relevant papers.

4 Findings and Discussion

4.1 Distribution of literature

As seen in table 1, over 70% of relevant publications are extracted from (1) Journal of Automation in Construction, (2) Advanced Engineering Informatics, (3) Journal of Computing in Civil Engineering, (4) Computer Aided Civil & Infrastructure Engineering, (5) Journal of Construction Engineering & Management, and (6) Electronic Journal of Information Technology in Construction. The former five are five prominent construction
management journals (Wing, 1997); the latter is a peer reviewed journal that published frequently cited papers on DTs. Contribution of research from United States, United Kingdom, and South Korea, was considerably higher in relative to other countries on the list (Figure 3). In addition, an increase in the number of papers published between 1998 and 2018 (Figure 4) indicates growing interest towards DT applications to construction industry.

**Table 1: Number of papers by journal source**

<table>
<thead>
<tr>
<th>Source</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automation in Construction</td>
<td>60</td>
</tr>
<tr>
<td>Advanced Engineering Informatics</td>
<td>14</td>
</tr>
<tr>
<td>Journal of Computing in Civil Engineering</td>
<td>12</td>
</tr>
<tr>
<td>Computer Aided/Civil and Infrastructure Engineering</td>
<td>9</td>
</tr>
<tr>
<td>Electronic Journal of Information Technology in Construction</td>
<td>8</td>
</tr>
<tr>
<td>Journal of Construction Engineering and Management</td>
<td>5</td>
</tr>
<tr>
<td>Construction Management and Economics</td>
<td>5</td>
</tr>
<tr>
<td>Architectural Engineering and Design Management</td>
<td>4</td>
</tr>
<tr>
<td>Journal of Management in Engineering</td>
<td>4</td>
</tr>
<tr>
<td>Building and Environment</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Construction And Architectural Management</td>
<td>3</td>
</tr>
<tr>
<td>Supply Chain Management</td>
<td>3</td>
</tr>
<tr>
<td>Advances in Engineering Software</td>
<td>1</td>
</tr>
<tr>
<td>Canadian Journal of Civil Engineering</td>
<td>1</td>
</tr>
<tr>
<td>Computers in Industry</td>
<td>1</td>
</tr>
<tr>
<td>Construction Innovation</td>
<td>1</td>
</tr>
<tr>
<td>European Journal of Purchasing and Supply Management</td>
<td>1</td>
</tr>
<tr>
<td>International Journal of Project Management</td>
<td>1</td>
</tr>
<tr>
<td>Expert Systems with Applications</td>
<td>1</td>
</tr>
<tr>
<td>Journal of Purchasing and Supply Management</td>
<td>1</td>
</tr>
<tr>
<td>Scientia Iranica</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>133</strong></td>
</tr>
</tbody>
</table>

Although the trend is similar as observed in similar studies by Shi et al. (2016) and Guo et al. (2017), there is a drop in the number of relevant publications after 2013 in Figure 4, which may not reflect the actual research trends. A probable reason is in the query term that does not include the specific DT terms, such as BIM or RFID. So many recent papers focusing on one specific technology might be excluded, which in addition might cause the drop in Figure 4.

### 4.2 Digital technologies to support construction supply chain practices

Based on the literature review, twenty-two DTs were identified: 3D printing, agent technology, Big Data Analytics, case based reasoning (CBR), context aware computing, distributed object model, electronic data interchange (EDI), e-commerce technologies, geospatial technologies, intelligent systems, management support system (MSS), mobile terminals, multimedia technology, open source technologies, Real-Time Location System (RTLS) and proximity warning system (PWS) technologies, Web 2.0 technology, Web portal, Web services, WSN, Wireless technology, Wireless Sensor Network (WSN), and XML technology.

GIS and GPS are referred to as geospatial technologies (Zhou et al., 2012). Ruff & Holden (2003) and Li et al. (2016) grouped RFID, WLAN, Ultrasound, Infrared, as RTLS - PWS technologies. WSN include Ultra Wide Band (UWB), Bluetooth, and ZigBee (Zhou et al., 2013). Shi et al. (2016) classified PDA, mobile phones, wearable technology, tablets, computers/laptop, and general portable devices as mobile terminals. Web-based or internet enabled technologies such as cloud computing, enterprise resource planning (ERP), BIM, VR, web based project management (WBPM) are identified as intelligent systems by (Ibem & Laryea, 2014). E-commerce technologies include extra net, intra net, email, and computer aided design (CAD) (Zou & Seo, 2006). Consolidating such a taxonomy is challenging in handling the complexity, the consistency, and the representativeness. There are, probably always, different voices on the classification of DTs. For example, Valero et al. (2015) and Xue et al. (2018) regard UWB as a specific type of RFID for the construction industry, not a separate DT as in the paper. Another argument could be that open source technologies should be a collaboration model rather than an applicable DT. This is a conceptual paper so some concepts are overlapped. For example, case based reasoning (CBR) is a kind of big data analytics; Web portal is a part of web services, also a part of “web based project management” (classified under “intelligent systems” in the paper); XML is a communication protocol and included in many DTs.

A number of authors examined the development of integrated systems in which two or more technologies are combined to deliver process efficiency. For instance Tserg et al. (2005) demonstrated effectiveness of a barcode enabled PDA in enhancing information flow between offices and sites in a CSC environment. On a similar vein, Wang et al., (2007) prototyped a mobile supply chain application system, by integrating RFID, PDA, and web portals. Abedi et al. (2016) developed a system using Context-Aware, Cloud Computing, and BIM to support collaboration between supply chain parties. Use of DTs, such as web-services and open source technologies, provide a cost effective solution for integrating supply chain partners with a wide range of computing capabilities. Das et al. (2015) developed an affordable system using open standards and open source technologies for enhancing CSC collaboration.

Majority of research topics are oriented towards DTs applications in augmenting information flow (Ergen & Akinci, 2008); safety management (Demiralp et al., 2012); process visualisation (Irizarry et al., 2013); material flow and tracking (Ko et al., 2016); procurement activities (Kong et al., 2004); and supply chain integration (Cheng et al., 2012).
Based on the emerging aspects of CSC, authors developed a framework with five key aspects of CSC enabled by DTs. This is discussed in the next section.

### 4.3 Digital construction supply chain framework

Authors apply a combination of perspectives drawn from literature to propose a digital supply chain framework enabled by DTs. The framework, shown in figure 3, is intended to enable digitization of five aspects of the construction supply chain.

![Digital construction supply chain framework](image)

**Figure 5: Digital construction supply chain framework**

#### 4.3.1 Supply chain integration and collaboration

A primary objective of a digital supply chain is to deliver the right product to the right person at the right time and location (Kumaraswamy et al., 2004). This should happen by means of an integrated supply chain that connects suppliers, outsourcers, contractors, and customers, end to end. A number of cloud-based platforms enable the supply chain to interact with its stakeholders, much like functions of social media networks, leveraged by Web 2.0 technology. Through the network, participants are able to exchange real-time variables, such as information about inventories and financial data. This real-time feedback eliminates bottleneck along the supply chain by reducing delivery time, accidents, maintenance, and operation cost, while optimizing predictability and agility of the entire supply chain (Shi et al., 2016). BPM, web based ERP, and MSS integrate the supply chain by enabling collaborative decision making in complex construction project scenarios (Kumaraswamy et al., 2004). Further to this, integration can be enhanced by means of an RFID system that logs real time inventory data and improve short term forecasting and resilience of the system (Vukero et al., 2015). Better yet, Shin et al. (2011) found an RFID/WSN enabled CSC can offer a 32% improvement in time efficiency, in comparison to the traditional supply chain.

#### 4.3.2 Digital procurement and warehouse management

The procurement function of a supply chain is to manage the supply of raw materials. Digital warehousing or smart warehousing automates ordinary warehousing activities to transform inbound logistics, in particular goods delivery, driven through embedded sensor systems, to connect suppliers and customers. This practice actively mitigates supplier risk, manages planning process better, and improves sourcing on demand (Cheng et al., 2010). A survey of 603 respondents on the use of e-procurement system in the South African construction industry demonstrated e-commerce capabilities to facilitate intra and inter firm’s exchange of project information and data (Ibem & Laryea, 2015). Also as material and warehouse management are integral to supply chain process, implementing geospatial technologies enable mapping physical flow of goods, transportation cost management solution, and logistical constraints. This way digital platforms enable the procurement of digital supplies and services, without being restricted to acquiring only physical goods.

#### 4.3.3 Communication and information flow

Supply chain communication and information flow enables parties to work on interrelated activities in a collaborative environment and reduce construction conflicts (Tseng et al., 2005). DTs play a profound role in enhancing the supply chain communication and few case studies were previously mentioned in section 4.2. The traditional paper-based data interchange renders the construction industry prone to error, excessive time consumption, and high project costs. DTs, namely XML, EDI, and mobile technologies are considered to be instrumental to project coordination, communication, and data interchange (Issa et al., 2003). Min & Bjornsson (2008) modelled a virtual construction supply chain, leveraged by the agent technology to enable real-time information sharing among supply chain actors. Owing to their interactive, 3D dynamic visualisation capabilities, AR/VR facilitate real-time information communication on site, especially for large scale construction projects (X. Li, Yi, Chi, Wang, & Chan, 2018). From these perspectives, DTs point to the great potential for improving validity, timeliness, and flow of information between supply chain partners.

#### 4.3.4 Visual monitoring and logistics visibility in real time

Supply network visibility is the extent to which a member of the network is aware of the status of goods and services provided by suppliers and to its customers. The key to drive this visibility is through efficient information sharing among the members and reduce uncertainty (Briscoe & Dainty, 2005). Approximately 50% of the total cost of an industrial facility is associated with procurement, handling, and material storage (Young et al., 2011). Thanks to new technologies such as IoT, cloud computing and wireless web services, that are being rapidly used to track inventory and movement of goods indoors, such as warehouses (Daya et al., 2017). Visual representation facilitates monitoring resources in CSC, in real time. For instance, the integrated system of BIM and GIS developed by Irazary et al. (2013) visualised the status quo of material flow that not only detected delivery delays, but also minimized logistics costs (including cost of warehousing and transportation).

#### 4.3.5 Material and inventory management

Material management becomes complex as the project grows in size and material shortage when needed on site hamper overall project performance through delays and low productivity. DTs facilitate tracking and tracing delivery data items via cloud based platforms. A number of studies focused on RFID, GPS, and UWB based construction material management for efficient information delivery related to inventory management (Hinkka & Tätilä, 2013). DTs, leveraged by wireless technology, communicate the position and arrival of delivery items and equipment, auto allocate storage space for new delivery, and automate movement of materials to the right locations (Shin et al., 2011). The system constantly updates inventory in real time, thus optimize JIT delivery, while mapping the entire facility (Issa et al., 2003). In terms of material production, 3D printing provide for reducing material usage and shortening the supply chain. The implementation of these technologies drive the digital supply chain by an interconnected, vertical integration of business functions, and exchanging large amount of information to parties involves (Schober et al., 2016).
5 Conclusion and Further Research

This study is a literature-based theoretical exploration of DT applications in CSC. Based on a review of 133 papers between 1998 and 2018, the study identified twenty-two different kinds of DTs available to support basic CSC practices. Further to literature review results, authors proposed a framework with five aspects of construction supply chain collaboration and management. The findings of the study are intended to encourage digitalization in NZ construction in improving its supply chain efficiency. This in turn may directly address flow of materials and logistics concerns in the sector. The paper illustrates the role of DTs in this process. However, it is acknowledged that the review analysis is not exhaustive. The actual trend of DT applications in CSC may be further revised by applying a systematic search querying specific DT term names, such as BIM or RFID. This may indicate an increase in the actual trend of DT applications in CSC for further study.

In this paper, the digital CSC framework is derived from the qualitative review of literature. A quantitative analysis may be performed to validate the results. Another area that may be explored further is DT application using the SCOR model of construction supply chain. SCOR model links processes to performance metrics and might prove valuable to practitioners. It is, of course, meaningful to encourage DT applications in NZ building industry regarding the reported cases in the literature. Well, it is probably more valuable if some promising, yet not reported, DT applications can be identified and mentioned for future research. For instance, laser scanning, photogrammetry, and artificial intelligence toolkits can be potent in certain circumstances. In conclusion, the digital supply chain not only relies on technologies for its implementation, but also on building the right practices. The remodelling of the supply chain may be examined through lens of management practices and addressed in future research.

6 References


Schrauf, S., & Bertram, P. (2016). Industry 4.0: How digitization makes the supply chain more efficient, agile, and customer-focused. PWC. Retrieved from https://www.strategyand.pwc.com/Reports/industryIV0
The potentials of BIM are enormous. For example, Gayathri, Hinal, and Ranadewa (2013) identified some of its potentials to include: value added project delivery; integration of design and construction; adequate communication; and improved construction processes. Similarly, Yan and Damian (2008) asserted that BIM is a powerful management tool for design, project, construction, and facility which ensures collaboration between project stakeholders. In the same vein, productivity and effective communication between stakeholders can be enhanced by BIM (Becerik-Gerber and Rice, 2010). BIM, as described by some authors (Scott, Chong, and Li, 2005; Wong, 2012) is a universally accepted, readily available, and cost effective tool. It is widely accepted as an integrated system that simulates buildings’ behavior in real world providing accurate information about building elements, quantities and design information in an integrated database (Royal Institute of British Architects, 2012; Ian and Bob, 2010; Sabol, 2008). Succar (2009) described BIM as the new Computer Aided Design (CAD) paradigm for design development, building maintenance and management, as well as project documentation.

Despite the outstanding capabilities of BIM, so many developing countries are yet to adopt it. The question now is - what are the possible reasons for its non-adoption? Kassim, Brogden, and Davwood (2002) asserted that identifying the barriers to BIM’s adoption could enhance its acceptance. Some of the factors that create barriers to its full implementation have been identified in the literature and are presented in Table 1.

Table 1. Barriers to BIM adoption
(Adapted from Hosseini, Azati, Tienadle, and Chileshe, 2017)

<table>
<thead>
<tr>
<th>Barriers to BIM</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of management support</td>
<td>Salem et al. 2005; Hudson, 2007</td>
</tr>
<tr>
<td>Cost of implementation (software and training)</td>
<td>BuildingsSMART, 2011; Abubakar et al., 2014; Rogers et al., 2015</td>
</tr>
<tr>
<td>Little of no effort from the government to adopt BIM</td>
<td>Olatunji, 2008; Alnawte, 2009; RICS, 2011</td>
</tr>
<tr>
<td>Interoperability</td>
<td>Nanajkar and Gao, 2014; Rogers et al., 2015</td>
</tr>
<tr>
<td>Lack of BIM education and experts</td>
<td>BuildingsSMART, 2011; Abubakar et al., 2014; Chan, 2014; Nanajkar and Gao, 2014; RICS, 2011</td>
</tr>
<tr>
<td>Lack of demand</td>
<td>Chan, 2014; Rogers et al., 2015; RICS, 2011</td>
</tr>
<tr>
<td>Lack of skilled personnel</td>
<td>BuildingsSMART, 2011; Chan, 2014; Rogers et al., 2015; Fox and Hotham, 2006</td>
</tr>
<tr>
<td>Resistance to change</td>
<td>Abubakar et al., 2014; Rogers et al., 2015</td>
</tr>
<tr>
<td>Lack of standards and guidelines</td>
<td>Technology bureau, 2013; Chan, 2014</td>
</tr>
<tr>
<td>Lack of support from policy makers</td>
<td>Bin Zakaria et al., 2013; Abubakar et al., 2014</td>
</tr>
<tr>
<td>Lack of knowledge</td>
<td>Bin Zakaria et al., 2013</td>
</tr>
<tr>
<td>Authenticity</td>
<td>Farman, and Khivuts, 2006; Christensen et al., 2007</td>
</tr>
<tr>
<td>Professional indemnity insurance</td>
<td>Wallbank, 2011</td>
</tr>
<tr>
<td>Product liability risk</td>
<td>Race, 2012</td>
</tr>
<tr>
<td>Contractual agreements</td>
<td>Eadie et al., 2010; Breezke and Hovinka, 2009; Christensen et al., 2007; Iden, 2012; RICS, 2011</td>
</tr>
<tr>
<td>Ownership and intellectual rights</td>
<td>Olatunji, 2012</td>
</tr>
</tbody>
</table>

Eastman et al (2011) categorized the barriers into process and technology barriers. The former includes legal and organizational issues while the latter involves readiness and implementation. According to Hosseini et al. (2016), the major barriers of BIM adoption as observed in some developing countries are lack of awareness and unavailability of training and skilled personnel. To ensure successful adoption of BIM, drivers such as BIM software availability and affordability, awareness of the technology, government support through legislation, clients’ interest, cooperation and commitment, collaborative procurement, and proof of cost savings by its adoption (Abubakar et al., 2014) have to be in place. With the full potentials of BIM, developing countries can gainfully deploy BIM for their construction industries.

The drivers and barriers of BIM adoption across developing countries varies but are quite similar. It is imperative to identify them as they relate to each country to ensure successful transition. A study by Mu’awia (2013) identified lack of awareness of BIM technology among Nigerian building professionals as one of the important barriers of BIM adoption in Nigeria. Similarly, a study conducted in Ghana revealed about 6.89% of the respondents had proficient knowledge of BIM (Armah, 2015). In contrast, Kiprotich’s (2014) study indicated high level of BIM awareness among South African construction professionals. Likewise, Ugochukwu, Akabogu, and Okolie (2015) reported a high rate (67%) of BIM awareness in Anambra and Enugu States of Nigeria. However, these studies indicate varying level of adoption across developing countries. Hence, the need to assess the level of BIM awareness especially in Nigeria.

The Nigerian construction industry especially the Architecture, Engineering and Construction (AEC) sector is faced with so many challenges. Majority of the problems encountered on Nigerian sites can be traced to miscommunication and inadequate information (Ryal-Net and Kaduma, 2015). BIM is a potent technology to enhance effective communication among other things if fully adopted. Although some professionals in the Nigerian AEC sector are appreciably ready for the adoption of BIM (Mu’awia, 2013), but there are some specific barriers. Therefore, this study aims to identify the drivers and barriers of adopting BIM in the Nigerian AEC industry. The study is limited to Lagos being the state with most construction activities (Oladapo, 2006). In order to achieve the aim of the study, the specific objectives are:

- To assess the level of awareness of BIM by the Nigerian AEC professionals
- To identify and rank the most suitable driver of BIM in the Nigerian AEC industry
- To identify and rank the barriers of BIM adoption in the Nigerian AEC industry

2 Research Methodology

The research methodology involves the procedure employed to achieve the aim and objectives of the study. The study reviews extant literature on BIM technology, its barriers, and drivers as well as the Nigerian construction industry and AEC industry. The review guides the development of the research instrument adopted. A quantitative research method through structured questionnaire was employed for data collection and analysis. The sample frame consists of practicing professionals (architects, civil/structural engineers and building contractors) in registered AEC firms in Ikeja Local Government Area of Lagos state, Nigeria. Due to the large number (1075) of AEC firms in Lagos (VConnect, 2016), a sample size of 92 was obtained using Yemane’s (1967) sample size calculation.

Table 2. Analysis of questionnaire distribution

<table>
<thead>
<tr>
<th>Respondents</th>
<th>No of questionnaire distributed</th>
<th>No of questionnaire retrieved</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Architects</td>
<td>50</td>
<td>25</td>
<td>83.3</td>
</tr>
<tr>
<td>Civil/Structural engineers</td>
<td>30</td>
<td>22</td>
<td>73.3</td>
</tr>
<tr>
<td>Building contractors</td>
<td>40</td>
<td>27</td>
<td>67.5</td>
</tr>
<tr>
<td>Total</td>
<td>125</td>
<td>74</td>
<td>70.5</td>
</tr>
</tbody>
</table>

A total of 105 questionnaires were administered to obtain expert opinions. However, only 74 were duly completed and returned representing 70.5% as shown in Table 2. The responses were assessed on a five-point Likert scale, where 1 = strongly disagree, 2 =
disagree, 3 = average, 4 = agree, and 5 = strongly agree. Data collected were analysed using the mean item score which was calculated by adding all the values in the group rankings and then dividing the result by the number of respondents.

3 Findings and Discussion

3.1 Demographic profile of respondents

The demographic profile of respondents as shown in Table 3 include their academic qualifications, years of experience, and type of services offered. The result of their academic qualifications reveal that 5.4%, 43.5%, 48.6%, and 2.7% have attained higher national diploma (HND), Bachelor of Science (B.Sc), Master of Science (M.Sc), and Doctor of Philosophy (Ph.D) respectively. This implies that the respondents have requisite educational qualification to provide relevant information. The result of respondents’ years of experience reveal that 36.5% had experience between 1-5 years, 28.5% had experience between 6-10 years, 24.3% had experience between 11-15 years, 8.1% had experience between 16-20 years while 2.7% had experience above 20 years. Since majority of the respondents have recent experience, the result of this study will be accurate. The type of services offered varies across all professionals surveyed. Table 3 reveals that 41.9% of the respondents offered building works, 25.7% offered consultancy, 14.9% offered civil engineering and project management works, while 2.7% offered worked as consortium. This shows that information provided by the respondents are relevant owing to the fact that majority offered building works.

Table 3. Respondents’ Data

<table>
<thead>
<tr>
<th>Category</th>
<th>Classification</th>
<th>Frequency</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Qualification</td>
<td>HND</td>
<td>4</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>B.Sc, B.Tech.</td>
<td>32</td>
<td>43.3</td>
</tr>
<tr>
<td></td>
<td>M.Sc, M.Tech.</td>
<td>36</td>
<td>48.6</td>
</tr>
<tr>
<td></td>
<td>Ph.D</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>Years of experience</td>
<td>1-5 years</td>
<td>27</td>
<td>36.5</td>
</tr>
<tr>
<td></td>
<td>6-10 years</td>
<td>21</td>
<td>28.4</td>
</tr>
<tr>
<td></td>
<td>11-15 years</td>
<td>18</td>
<td>24.3</td>
</tr>
<tr>
<td></td>
<td>16-20 years</td>
<td>6</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>Above 20 years</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>Types of services offered</td>
<td>Building works</td>
<td>31</td>
<td>41.9</td>
</tr>
<tr>
<td></td>
<td>Civil engineering works</td>
<td>11</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Project Management</td>
<td>11</td>
<td>14.9</td>
</tr>
<tr>
<td></td>
<td>Consortium</td>
<td>2</td>
<td>2.7</td>
</tr>
</tbody>
</table>

3.2 BIM Awareness

The awareness of BIM among construction professionals in Nigeria has been reported to be low. For example, Ryal-Net and Kaduna (2014) reported awareness level of 32.6%. The respondents in the study were asked to respond yes or no to a question on their awareness of BIM. The result indicates that 43 (58.1%) of the respondents revealed that they are aware of BIM and have deployed BIM technology in at least one of their projects. On the other hand, 31 (41.9%) of the respondents revealed that they have no idea about BIM. The high level of BIM awareness among Nigerian AEC professionals as uncovered in this study aligns with the findings of Ugochuckwu et al (2015) of 67% BIM awareness level.

3.2.1 Organisations’ use of BIM

Sequel to the high level of BIM awareness among AEC professionals, respondents who indicated their awareness of BIM were asked if they use BIM technology in their organisations. The result reveals that 19 (25.7%) of the respondents use BIM technology especially Revit Architecture software. Meanwhile, 24 (32.4%) indicated that they do not use any BIM technology in their organization. This implies that despite the high level of awareness, the use of BIM technology is low among Nigerian AEC companies. Some of the barriers identified by the respondents are discussed in section 3.3.

3.2.2 Level of understating of BIM

Those respondents that are aware of BIM were further asked to rate their level of understanding of the concept of BIM on a scale of 10 with one (1) being the lowest and 10, the highest. The result as presented in Table 4 reveals that majority (18.9%) of the respondents are just a little above the half mark line in terms of their knowledge of BIM. However, none of the respondents claim to have excellent knowledge of BIM. Despite the high level of awareness among Nigerian AEC professionals, this results suggests that there is need for more education and training on BIM.

Table 4. Level of understanding of BIM

<table>
<thead>
<tr>
<th>Rating</th>
<th>Frequency</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4.1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>5.4</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>8.1</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>10.8</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>18.9</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>6.8</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>2.7</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>43</td>
<td>58.1</td>
</tr>
</tbody>
</table>

3.3 Barriers to BIM adoption in the Nigerian AEC Industry

Table 5 shows the barriers to BIM adoption in the Nigerian AEC industry. Respondents were asked to rate their level of agreement to a list of barriers adopted from the literature on a five point Likert scale with values ranging from 1 to 5 (1 = strongly disagree and 5 = strongly agree). The average weight for each factor (barrier) was calculated and presented in Table 5. The results revealed that lack of awareness with mean score 4.23 was identified as the most important barrier to BIM adoption in the Nigerian AEC industry. Other barriers and how they rank are presented in Table 5.
This finding is similar to that reported by Mu’awiya (2013), Ryal-Net and Kaduma (2015), Akerele and Etienne (2016), and Ugochukwu et al. (2015). The lack of awareness of BIM among AEC professionals may be the reason why the Nigerian building industry is yet to fully adopt it (Ibrahim and Bishir, 2012). On the flip side, suitability of BIM for Nigerian projects (mean score = 2.37) was identified as the least ranked barrier. Worthy of note among the barriers are lack of trained professionals (mean score = 4.19), cost of software (mean score = 4.07), and lack of clients’ demand (mean score = 4.05).

The barriers of BIM adoption are categorized into management, process, financial, people, technology, and legal barriers as adopted from the literature and shown in Table 6. As for management barrier, lack of awareness was ranked most while lack of supply chain buy-in was ranked least by the respondents. Poor power supply which is one of the challenges faced by most businesses in Nigeria was ranked as most process barrier while suitability of BIM for Nigerian projects was ranked least. Majority of the respondents disagreed that BIM is not suitable for projects in Nigeria. Cost of software, cost of training, and lack of assured return on investment were ranked 1st, 2nd, and 3rd simultaneously for financial barriers. Dearth of trained BIM professionals was ranked as most barrier encountered based on people’s involvement while majority of the respondents disprove the fact that BIM wastes human resources. As for technology barriers, lack of adequate ICT infrastructure and lack of design constructability were ranked most and least respectively (see Table 6).

In order to determine the most and least category of barriers to BIM adoption in the Nigerian AEC industry, the mean score of each category were analysed. As shown in table 7, management barrier with mean score 3.98 was ranked most while process barrier with mean score 3.01 was ranked least. All categories of barriers need further research on technology and process barriers. This clearly indicates the need for urgent actions to break those barriers.

### Table 5. Barriers to BIM adoption in the Nigerian AEC industry

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Mean</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of awareness</td>
<td>4.23</td>
<td>1</td>
</tr>
<tr>
<td>Lack of trained professionals</td>
<td>4.19</td>
<td>2</td>
</tr>
<tr>
<td>Lack of top software</td>
<td>4.07</td>
<td>3</td>
</tr>
<tr>
<td>Lack of clients demand</td>
<td>4.05</td>
<td>4</td>
</tr>
<tr>
<td>ICT illiteracy</td>
<td>3.98</td>
<td>5</td>
</tr>
<tr>
<td>Lack of training</td>
<td>3.95</td>
<td>6</td>
</tr>
<tr>
<td>Lack of adequate ICT infrastructure</td>
<td>3.93</td>
<td>7</td>
</tr>
<tr>
<td>Lack of top management support and commitment</td>
<td>3.86</td>
<td>8</td>
</tr>
<tr>
<td>Uncertainty in interoperability among software</td>
<td>3.84</td>
<td>9</td>
</tr>
<tr>
<td>Ownership and intellectual property</td>
<td>3.84</td>
<td>10</td>
</tr>
<tr>
<td>Lack of supply chain buy-in</td>
<td>3.77</td>
<td>11</td>
</tr>
<tr>
<td>Contractual arrangement</td>
<td>3.74</td>
<td>12</td>
</tr>
<tr>
<td>Product Liability Risk</td>
<td>3.70</td>
<td>13</td>
</tr>
<tr>
<td>Lack of assured return on investment</td>
<td>3.58</td>
<td>14</td>
</tr>
<tr>
<td>Poor power supply</td>
<td>3.49</td>
<td>15</td>
</tr>
<tr>
<td>Authenticity</td>
<td>3.47</td>
<td>16</td>
</tr>
<tr>
<td>Professional Indemnity Insurance</td>
<td>3.44</td>
<td>17</td>
</tr>
<tr>
<td>Risk of using a single model</td>
<td>3.28</td>
<td>18</td>
</tr>
<tr>
<td>Reluctance to change existing work practice</td>
<td>3.16</td>
<td>19</td>
</tr>
<tr>
<td>Other competing innovations</td>
<td>3.16</td>
<td>20</td>
</tr>
<tr>
<td>Slows down the design process</td>
<td>2.93</td>
<td>21</td>
</tr>
<tr>
<td>Waste human resource</td>
<td>2.88</td>
<td>22</td>
</tr>
<tr>
<td>Lack of design constructability</td>
<td>2.88</td>
<td>23</td>
</tr>
<tr>
<td>Poor project definition</td>
<td>2.84</td>
<td>24</td>
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<tr>
<td>Suitability of BIM for Nigerian projects</td>
<td>2.37</td>
<td>25</td>
</tr>
</tbody>
</table>

### Table 6. Category of barriers to BIM adoption

<table>
<thead>
<tr>
<th>Category of barrier</th>
<th>Mean</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management barrier</td>
<td>4.23</td>
<td>1</td>
</tr>
<tr>
<td>Lack of awareness</td>
<td>4.23</td>
<td>2</td>
</tr>
<tr>
<td>Lack of clients demand</td>
<td>4.05</td>
<td>3</td>
</tr>
<tr>
<td>Lack of top management support and commitment</td>
<td>3.86</td>
<td>4</td>
</tr>
<tr>
<td>Lack of supply chain buy-in</td>
<td>3.77</td>
<td>5</td>
</tr>
<tr>
<td>Poor power supply</td>
<td>3.49</td>
<td>6</td>
</tr>
<tr>
<td>Risk of using a single model</td>
<td>3.28</td>
<td>7</td>
</tr>
<tr>
<td>Reluctance to change existing work practice</td>
<td>3.16</td>
<td>8</td>
</tr>
<tr>
<td>Slows down the design process</td>
<td>2.93</td>
<td>9</td>
</tr>
<tr>
<td>Lack of assurance</td>
<td>3.84</td>
<td>10</td>
</tr>
<tr>
<td>Product Liability Risk</td>
<td>3.70</td>
<td>11</td>
</tr>
<tr>
<td>Lack of assured return on investment</td>
<td>3.58</td>
<td>12</td>
</tr>
<tr>
<td>Poor power supply</td>
<td>3.49</td>
<td>13</td>
</tr>
<tr>
<td>Authenticity</td>
<td>3.47</td>
<td>14</td>
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<tr>
<td>Professional Indemnity Insurance</td>
<td>3.44</td>
<td>15</td>
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<tr>
<td>Risk of using a single model</td>
<td>3.28</td>
<td>16</td>
</tr>
<tr>
<td>Reluctance to change existing work practice</td>
<td>3.16</td>
<td>17</td>
</tr>
<tr>
<td>Other competing innovations</td>
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<tr>
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</tr>
<tr>
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<td>Poor project definition</td>
<td>2.84</td>
<td>22</td>
</tr>
<tr>
<td>Suitability of BIM for Nigerian projects</td>
<td>2.37</td>
<td>23</td>
</tr>
</tbody>
</table>

### Table 7. Category of barriers

<table>
<thead>
<tr>
<th>Category of barrier</th>
<th>Mean</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management barrier</td>
<td>3.98</td>
<td>1</td>
</tr>
<tr>
<td>Financial barrier</td>
<td>3.68</td>
<td>2</td>
</tr>
<tr>
<td>People barrier</td>
<td>3.68</td>
<td>3</td>
</tr>
<tr>
<td>Legal barrier</td>
<td>3.64</td>
<td>4</td>
</tr>
<tr>
<td>Technology barrier</td>
<td>3.45</td>
<td>5</td>
</tr>
<tr>
<td>Process barrier</td>
<td>3.03</td>
<td>6</td>
</tr>
</tbody>
</table>

### 3.4 Drivers of BIM adoption in the Nigerian AEC Industry

Having identified the barriers of BIM adoption, it is important to identify the drivers in order to fast track the adoption process. Therefore, respondents were asked to rate their level of agreement to a list of drivers adopted from the literature on a five point Likert scale. The result indicates that majority of the respondents agreed that the desire for innovation in order to remain competitive is a major driver which can be attributed to the modernization and revolutionary experiences. Alongside the desire was the capacity to ease design activities and improve design quality which aligns with the findings of Bazjarac (2005) and Bjork (2010) that BIM can lead to an improved design and buildability. Ability to provide life cycle value to clients ranked third (see Table 8) which supports the findings of Azhar et al. (2011) that the most advanced BIM products currently...
available have the capability to deliver environmental, energy, cost, schedule and spatial analysis and as such, can be used collaboratively to deliver real whole life value to clients. However, the respondents strongly disagreed that the government was taking bold steps to enhance the implementation of BIM and this complements Olatunji (2008) and Alinaitwe (2009) research findings that government bureaucracy, inconsistency in policies, lack of social amenities and infrastructure are barriers to BIM implementation in Nigeria. It was also observed that there have not been much support from the top managements to implement BIM. The respondents also disagreed that clients are interested in the use of BIM for their projects.

Table 8. Drivers of BIM adoption in the Nigerian AEC industry

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Mean</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desire for innovation in order to remain competitive</td>
<td>3.91</td>
<td>1</td>
</tr>
<tr>
<td>Capacity to ease design activities and improve design quality</td>
<td>3.86</td>
<td>2</td>
</tr>
<tr>
<td>Ability to provide lifecycle value to clients</td>
<td>3.82</td>
<td>3</td>
</tr>
<tr>
<td>Top management support and commitment</td>
<td>3.33</td>
<td>4</td>
</tr>
<tr>
<td>Commitment and cooperation of professional bodies</td>
<td>3.33</td>
<td>4</td>
</tr>
<tr>
<td>Availability of trained professionals</td>
<td>3.28</td>
<td>6</td>
</tr>
<tr>
<td>Clients interest in the use of BIM in their projects</td>
<td>2.84</td>
<td>7</td>
</tr>
<tr>
<td>Pressure from the government to adopt BIM technology in projects</td>
<td>2.58</td>
<td>8</td>
</tr>
</tbody>
</table>

4 Conclusion and Further Research

This study has explored the barriers and drivers of BIM adoption in the Nigerian AEC industry. It revealed that ‘lack of awareness (mean score 4.23)’, ‘lack of trained professionals (mean score 4.19)’, and ‘cost of software (mean score 4.07)’ were the most significant barriers to the adoption of BIM. The barriers were categorized into six, namely: management barriers, process barriers, financial barriers, people barriers, technology barriers, and legal barriers. Of these categories, management and process barriers are the most and least barriers to the adoption of BIM respectively. On the flip side, ‘desire for innovation (mean score 3.91)’, ‘capacity to ease design activities and improve design quality (mean score 3.86)’, and ‘ability to provide lifecycle value to clients (mean score 3.67)’ were found to be the main drivers of BIM adoption. The study also assessed the awareness and understanding level of BIM among AEC professionals. The findings revealed medium level (58.1%) of awareness and that majority of those that are aware of BIM possess little understanding of its techniques.

The results discussed in this study may not be generalizeable to the Nigerian construction industry because only AEC professionals in Ikeja, Lagos State, Nigeria were consulted. However, the study is significant as it draws attention to the awareness level of BIM, understanding level of BIM technology, barriers, and drivers of BIM adoption in the Nigerian AEC industry. Since there is medium level of BIM awareness, the study suggests consistent increased awareness among AEC professionals and clients through diverse fora. Government and professional institutes may embark on vigorous campaigns, sensitization programmes and training of AEC professionals and clients on the benefits of BIM to the industry, environment, clients, and the country. Further research is recommended on improving clients’ awareness and adoption of BIM. More so, simplified BIM training techniques and adoption framework are other areas for future research work.

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Application of wearable augmented reality system in expressway inspection

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Abstract:
This paper presents a proposed application of wearable augmented reality (AR) system called HoloSpector which can be deployed to Microsoft HoloLens and employed in expressway inspection of the Expressway Authority of Thailand (EXAT). The primary aim of this proposed research is to develop an application of wearable AR system to facilitate the process of onsite condition assessment of an expressway in Thailand and to enhance the EXAT’s current practices of onsite inspection operations. To achieve the research objectives, proposed procedures, the development workflow of HoloSpector application, and a proposed acceptance model are going to be carried out. The application of wearable AR system will be tested and assessed by 2 groups of individuals: inexperienced and experienced. 25 graduate students will be recruited, and 5 expert inspectors from EXAT who are experienced personnel will be also invited. The study will result in a useful and easy-to-use application which can be applied in onsite inspection and condition assessment process conducted by EXAT. More significantly, the application will reduce time and cost involved in the inspection activities, create a safer inspection since the HoloLens enables hands-free inspection, generate an effective data collection and management, enhance efficiency, productivity and quality of expressway inspection, and digitalize the inspection process. Further studies are needed to enhance the capabilities and functionalities of the application of wearable AR system in the activities of expressway inspection.

Keywords: application, augmented reality system, expressway, inspection, wearable.

1 Introduction

Augmented reality (AR) has been typically known as the superimposition of digital contents or digitally simulated objects over the physical environment. In practice, it has been noticed that AR technology has been utilized and adopted in various fields, namely medical fields, museum, military, maintenance, manufacture, visualization, gaming industries and entertainment, robotics, training and education, marketing and advertising, travel and tourism industry, urban planning, architectural and civil engineering fields, etc.

In the old days, wearable AR and construction industry were far apart from one another. However, the new trends of these two worlds have been collaborate so fast in these days. Certain industries have greatly invested in AR technology which is believed to be an effective and innovative solution to digitally visualize the 3D infrastructure models. For instance, an electrical engineer is able to see all the cables in the walls of a building via AR devices. Technically, AR headsets digitally allow the user to augment and interact with computer-generated images or objects which are projected into the existing environment. In this technological age, a wearable AR device which is Microsoft HoloLens, compared to other wearable devices, can be essentially used as an effective tool in various fields, namely education, training, architecture and design, manufacture, construction, gaming industries, entertainment, science and engineering, and so on. Practically, HoloLens provides the user unique experiences to control their holography in real-time, the user can actually interact with holograms or digital contents in the real world by utilizing gesture, voice commands and gaze. Essentially, a HoloLens user can share his or her holograms and digital contents remotely with other HoloLenses’ users in real time. This wearable headset will transform the ways of communication, creation, innovation, collaboration, and exploration to bring ideas to life.

As a matter of fact, the infrastructure contains so much information that the inspector finds it difficult to access that information. In this case, AR system plays a dominant role in the inspection activities by allowing the inspector and relevant individuals to project and simultaneously interact with the necessary digital data and information in the real-world environment and in real time. Globally, urban infrastructures are highly needed to alleviate traffic, gridlocks and congestion in metropolises. It has been seen that Thailand has a significant growth of new civil infrastructure, namely roads, rails, bridges, elevated expressways and highways, etc. In Thailand, it has been noticed that expressways are more widely used since they serve people as time saver and allow them to travel safely, efficiently and conveniently. Remarkably, the annual number of cars and vehicles on the road has increased significantly, leading to the increased use of the expressways. Inevitably, the physical structure of the expressway might be to some extent damaged and defected when they have been put into extensive use. Therefore, it is vital and necessary to technically inspect and maintain the expressway structures to ensure the safety for all users as well as general public. Service life and deterioration, known as the two factors of expressway’s strength, have been considered fundamental concerns for structural inspections; thus, it requires inspection of structures which are the methods used to evaluate any conditions of the existing expressways. A cost-effective inspection system will analyse and suggest effective solutions to solve deficiencies on the expressway.

In the present days, the designs are indeed represented as line-based paper drawings and to some extent projected on portable displays. Hence, AR system can be a key and problem solver for engineers to inspect as well as to maintain the built environment with visualization in the real-world practices. In point of fact, it is demonstrated that AR has been practically employed in many sectors and industries as mentioned above. However, the use of advanced AR headset such as HoloLens is still limited in the infrastructure inspection. In spite of the fact that AR technology as research topics are on rise, there is indeed limited research on applications of wearable AR system that can be employed in the current practices of infrastructure inspection, specifically expressway inspection. Moreover, the extensive use of AR technology is rarely evident in the existing practices of expressway inspection. Academically, the existing studies are still in its infancy. In particular, the existing inspection practices are however primarily conducted and employed outdated approaches or AR systems that are specifically time-consuming in accessing and recording the data or information of infrastructure for effective inspections. Indeed, more work is required to realise and capitalise on the benefits of this technology within the infrastructure inspection as well as the construction industry.
The current proposed study will be carried out to achieve the following objectives:

1. To adopt AR technology to be applied in on-site inspection of an expressway in Thailand by employing Microsoft HoloLens and to digitalize a new way of expressway inspection;
2. To examine the current issues and challenges occurred during expressway inspection and condition assessment procedures performed by the EXAT;
3. To facilitate and enhance understanding, productivity and quality of the current expressway inspection and condition assessment practices conducted by the EXAT by adopting a wearable AR system;
4. To determine how AR technology can assist in the expressway’s onsite inspection and condition assessment activities; and
5. To investigate whether AR technology offers potential for inspection tasks in comparison to conventional approaches and techniques.

In summary, this study aims to develop an effective, user-friendly and practical application of wearable AR system that can be used to enhance and facilitate the current operations of onsite inspection and condition assessment of an expressway. It will promote a safer inspection and create an effective data collection and management so that the inspector and relevant individuals can retrieve necessary information and data from the system to further investigate certain deficiencies and solve certain issues of the expressway’s physical infrastructures. Accordingly, the system plays a significant role in preparing the users to become expert inspectors in this technological age and be ready to adopt the advanced technology of AR in the inspection activities. In expressway inspection, it is believed that AR and HoloLens can potentially assist engineers and inspectors to inspect the physical structure of expressway in a timely and efficient manner at the site.

In terms of the scope, this proposed research will focus on expressway infrastructure networks that are currently managed by the EXAT. In addition, this study will focus on the inspection and condition assessment of expressway structures. Specific structures will be selected in consultation with EXAT’s expert inspectors and engineers. The research will also focus on the aspect of information management and communication of the inspection process between the onsite operation and the head office. The research will not deal with the mechanical system or drainage system and technicality of the actual repair works carried out as a result of the condition assessment.

2 Literature Review
2.1 Overview of expressway infrastructure inspection and maintenance
Expressways and bridges play a dominant role in lessening traffic, gridlocks and congestion, and the road users find expressways convenient to travel from destinations to destinations. In Thailand, people who wish to save time when traveling in Bangkok will find the expressways efficient and helpful. Noticeably, the annual number of cars and vehicles on the road has increased significantly, leading to the increase in using the expressways. Inevitably, the physical structures of the expressway might be to some extent damaged and defected when they have been put into extensive use. Therefore, it is necessary to technically and routinely inspect and maintain the expressway structures to ensure the safety of all users as well as general public.

2.2 Augmented reality
Augmented Reality (AR) has been commonly known as the superimposition of virtual contents into the real environment; in order words, it is a technology that combines the real-world and computer-generated data to create an environment where data generated by a computer is inserted into the user’s view of a real-world scene. AR allows a user to perform tasks in a real-world environment while visually receiving additional computer-generated information to support the tasks at hand (Wang et al., 2013). More significantly, AR enriches users’ perception of and interaction with the real world. The information conveyed by the virtual objects helps the user perform the real-world tasks efficiently and potentially. It has been known that AR technology can be utilised in many fields such as medical, military, manufacture, education, marketing, tourism, urban planning and civil engineering, and so on. Figure 1 illustrates a screenshot of a 3D model of hot-rolled steel connection that is augmented into the real world.

Technically, the strength of the expressway consists of two factors: service life and deterioration which place importance on structural inspection. Methods used for evaluating any conditions of the existing expressways are generally known as inspection of structures. In addition to this, the process of evaluation must be precise and accurate in order to enhance safe conditions to the traffic system and user comfort. As a matter of fact, a cost-effective inspection system will analyse and suggest effective solutions to solve deficiencies on the expressway.

Currently, the ETA (Expressway & Rapid Transit Authority of Thailand) has been using an inspection and maintenance system derived from the Japan International Cooperation Agency (JICA) system since 1994. Such inspection is divided into 3 classes: Daily inspection, Routine inspection and Special inspection.

- Daily inspection is known as a visual inspection overlooking from a moving vehicle, and an inspector should be someone who has a perfect vision or corrected vision.
- Routine inspection is also a visual inspection ranging from walking condition survey to using special equipment, and it is routinely conducted with the purpose of collecting the condition data of different structural components which are the main load-carrying components.
- Special inspection is the comprehensive test conducted after the daily and routine inspection by visual inspection. Maintenance and repair are generally carried out in three aspects. Firstly, “Routine Maintenance” covers cleaning of traffic sign, road sign, surface drainage system, lighting lamp, changing of road sign, painting of steel rail and small repairs on a regular basis according to the planned schedule. Secondly, “Corrective Maintenance” relies on the actual damage, namely the restoration of the road surface, road surface joint, retaining wall joint, gloss the chap, seal cracks on concrete structures, replacement of bulbs, electric light wire, toll collection device repair, emergency phone system, vehicle management system and damaged signs. Lastly, “Urgent Maintenance” is conducted on the damage from incidents such as damage caused by accident, fire, chemicals, so on and so forth. This is in order for the traffic on the expressway to be able to move easily and perform the permanent urgent maintenance for the expressway’s damage structure and component to resume back to normal.
2.3 Wearable augmented reality in construction industry and infrastructure

In civil engineering, a research was conducted to augment contextual information and maintenance data on real views of facility in bridge inspection (Hammad et al., 2004). Additionally, to avoid buried utilities and underground components of built infrastructure, a system was presented to demonstrate the potential of AR in assisting maintenance workers to detect existing underground utilities (Webster et al., 1996).

In the past, wearable AR and construction industry were far apart from one another. However, the new trends of these two worlds have been collaborated so fast in these days. Some industries have greatly invested in AR technologies that are believed to be effective and innovative solutions to digitally visualize the 3D infrastructure models. For instance, Building Information Modelling (BIM) can be integrated with wearable AR devices to exploit its capabilities to capture the whole lifecycle of real estate, an industrial building or the infrastructure around it. Besides, the whole project is captured and designed in 3D and demonstrates all the details before the actual work starts in the real site or environment. In practice, an electrical engineer will be able to see all of the cables in the walls of a building that is designed and built via the BIM standard or any other required infrastructure information via AR glassware such as Microsoft HoloLens. This will help save money and time where the maintenance of building is concerned. Figure 2 illustrates the digital inspection menu for expressway inspection and condition assessment projected into the real-world environment by a user wearing the Microsoft HoloLens.

3 Research Methodology

This research aims to adopt and integrate an AR system with a wearable and completely-un tethered HoloLens. To realize the research goal, the researchers propose research procedures, the development workflow of HoloSpector application and an acceptance model as described in the following sections.

3.1 Proposed procedures

3.1.1 Task 1: Review of existing research and literature

In this task, an extensive and critical review of literature was conducted to compile and better understand the knowledge on research pertinent to:

- The inspection of highway/expressway infrastructure, particularly its structures;
- The applications of information technology in highway/expressway infrastructure; and
- AR applications and development within various industries, with greater emphasis on engineering applications.

The primary objective of this task is to ensure that latest development and issues in AR applications in the inspection and condition assessment of highway/expressway infrastructure have been considered and incorporated into the development of the proposed study.

3.1.2 Task 2: Proof of concept

For this task, the proof of concept was conducted to examine how AR can be integrated and employed in an onsite inspection and condition assessment of EXAT’s expressway infrastructure assets. Specific research activities in this task include:

- A sample of AR application was created and tested to examine the applicability of AR in an onsite inspection and condition assessment; and
- Certain prototypes to be tested were developed and deployed to Microsoft HoloLens to measure the capabilities and potentials of the wearable device and developed applications.

The outcomes of this task are working prototypes of AR applications for various inspection and condition assessment activities.

3.1.3 Task 3: Exploratory study

It is vital to better understand the existing states of practice and knowledge in the inspection of highway/expressway infrastructure carried out in Thailand. For this task, an exploratory study will be conducted with the EXAT, and they will provide a collaborative support for this proposed research by allowing the researchers to obtain preliminary data/information relevant to the following topics:

- Current practices in inspection and condition assessment of EXAT’s expressway infrastructure assets;
- The use of information and communication technology (ICT) in EXAT’s inspection and condition assessment; and
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- Current issues and challenges in onsite inspection and condition assessment that are faced by EXAT’s inspectors and engineers.

The outcomes of this task will allow the researchers to establish a baseline understanding of EXAT’s current practices, against which the efficacy of the developed AR system will be measured.

3.1.4 Task 4: AR system development

Following the above proof of concept and exploratory study, an AR system will be developed for a complete inspection and condition assessment operation of a selected expressway structure that represents typical EXAT’s inspection works. To achieve this, the following research activities will be conducted:

- In consultation with the EXAT’s team, an inspection operation of an expressway structure section will be selected for which the AR system to be developed;
- A complete AR system will be designed and developed to capture the inspection and condition assessment of the selected structural section; and
- The developed system will be deployed to Microsoft HoloLens for onsite applications.

This task will produce a complete AR system that is equipped with the capabilities to enhance and facilitate the onsite inspection and condition assessment utilising real-time communication.

3.1.5 Task 5: AR system testing and evaluation

The AR system developed in the previous task will be tested to examine its efficacy under the actual inspection and condition assessment settings. For this task, graduate students and EXAT’s inspectors and maintenance engineers at different levels will be recruited to test and provide feedback on the developed AR system. The performance of the system will be assessed against specific criteria, which will be focused on user-friendliness, ability to aid the inspectors/engineers and MR&R teams, as well as any added value and benefits compared to the baseline practices. In particular, Technology Acceptance Model (TAM) will also be applied to assess the system to gain the perceptions, attitude, and behavioural intention of the recruited personnel when using the developed AR system. The outcome of this task will be in the form of an assessment report on the performance of the developed AR system.

3.2 Development workflow of HoloSpector application

A user-friendly, useful and practical holographic application to be developed is called “HoloSpector”. The development workflow of HoloSpector application is developed based on three main constructs: 3D asset creation, HoloSpector app development and HoloSpector app compiler deployment. The first construct provides 3D structures/contents for the HoloSpector application. The second construct is the designing stage of inspection menu and interactions between the user and the application. The last construct produces the final product of HoloSpector application to be deployed to HoloLens emulator for testing and then to Microsoft HoloLens (as shown in Figure 3) for actual onsite inspection and condition assessment activities. Figure 4 presents HoloSpector application development workflow.

3.3 Proposed acceptance model for wearable augmented reality system

As the application of wearable AR system utilizes AR technology to improve the inspection activities; therefore, it is essential to assess the AR system to gain the perceptions, attitude, and behavioural intention of the user towards the system as well as the technology usefulness and ease of use. Technology Acceptance Model (TAM) will be used in this proposed research (Davis, 1989). The test is basically the deployment of HoloSpector application to Microsoft HoloLens.

Figure 4. HoloSpector application development workflow
The process of proposed acceptance model consists of three main parts: participant selection, questionnaire design, and test result analysis and discussion. The system will be assessed by 30 participants: 25 graduate students from the school of Civil Engineering and Technology (CET) at Sirindhorn International Institute of Technology (SIIT), Thammasat University (TU), Thailand; and 5 expert inspectors from the Expressway Authority of Thailand (EXAT). A 7-point Likert scale will be utilized as a method for questionnaire evaluation. Afterwards, mean (M) and standard deviation (SD) will be determined after obtaining the questionnaire data to make a conclusion.

3.4 Research tools

3.4.1 Software for augmented reality application development
In the development of AR application for AR system, certain software and plug-ins have been used, namely Unity (Game engine – version 2017.3.1f.1), Vuforia, Microsoft Visual Studio Enterprise (version 2017), HoloLens emulator, Autodesk Maya, Autodesk 3ds Max, SketchUp, and AutoCAD.

3.4.2 Hardware for augmented reality application development
The hardware used for AR application include Microsoft HoloLens and a gaming laptop “Asus ROG G551J” running Windows 10 Education.

4 Expected outputs and outcome
The primary aim of this proposed study is to develop an AR system that can be practically and potentially used to enhance and facilitate the operations of onsite inspection and condition assessment of an expressway in Thailand. The main outcome of this research is a fully-developed AR system that can be applied to enhance and facilitate the current practices and activities of onsite inspection and condition assessment of expressway structures. In relation to this, the proposed research will produce many positive results include:

- The AR system that can be implemented in onsite inspection and condition assessment of a selected expressway carried out by the EXAT;
- The AR system that can reduce time and cost involved in the inspection procedures;
- It will create a safer inspection since the HoloLens enables hands-free inspection so that the inspector will be able to maintain the real-world view of the inspection/ construction site environment;
- It will generate an effective data collection and management in real time;
- It will enhance efficiency, productivity, quality, and accuracy of inspection;
- It will speed up the inspection process; and
- It will reduce labour intensive method and digitalize the paper-based approaches.

As mentioned in the section of proposed procedures, this proposed research consists of five research tasks, which can be summarized in Figure 5 below along with their associated outputs.

5 Conclusion and Further Research
The main focus of this proposed research is to adopt and integrate AR technology with Microsoft HoloLens in expressway inspection and condition assessment in an attempt to enhance the current practices of inspection and condition assessment performed by the EXAT and to cope with challenges and issues inherent in expressway inspection. With the use of wearable AR system: Microsoft HoloLens and developed HoloSpector application, it is believed to be a new and innovative approach for the EXAT to apply in the inspection of expressway structures in Thailand. In the current phase of this study, research task 1 and task 2 have been completely conducted. Besides, research task 3, task 4 and task 5 are currently being conducted.

6 Acknowledgement
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7 References
Teaching collaboration in tertiary BIM education: A review and analysis

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Abstract

Building Information Modelling (BIM) is inherently a team-based activity and possessing the Knowledge, Skills, and Abilities (KSAs) to collaborate across various disciplines and organisations are central for BIM-ready graduates. There is, nevertheless, no systematic attempt to analyse the current approaches to teaching collaboration KSAs across tertiary education institutions. This study is an attempt to provide an account of the current approaches taken by leading universities for training and educating collaboration, as a part of their BIM education programs. To this end, 63 articles on BIM education were identified, of which 18 were used to extract their practices to teaching collaboration. The content analysis of these studies revealed that the practices identified can be presented under 4 broad categories including Instructional approach, Prerequisites, Marking and evaluation, and Feedback, in which each category has various sub-categories. As the first in its kind, the present study provides an analysis and synthesis of the best practices for teaching educating collaboration, and therefore, assists educators and curriculum builders in integrating collaboration KSAs into BIM education in construction related curricula.

Keywords: Building Information Modelling (BIM), Collaboration, Education, Training, Curriculum, University.

1 Introduction

The BIM market is predicted to grow from US$3.16 billion in 2016 to US$7.64 billion in 2022, projecting an annual growth rate of over 16%. This presents the construction industry with multiple challenges, one being the task of ensuring construction firms are staffed with employees capable of handling the growing number of BIM-enabled projects across the industry. With such a pressing need to recruit BIM talents, it is important to focus on the exact competencies required. BIM implementation is inherently a team-based activity, strongly relying on interdisciplinary collaboration (Mignone et al., 2016). Lack of skill in multi-disciplinary collaboration has, therefore, become a major barrier to the successful use of BIM (Oraee et al., 2017). Despite the significance of collaboration skills, research on team member collaboration KSAs, and the best approaches for teaching and training the related KSAs have remained under-researched. Indeed, the current literature on the topic only comprises fragmented attempts for teaching collaboration at few universities (Merschbrock et al., 2018). An overall analysis of these attempts and creating an integrated illustration of the best practices is currently missing. This study is an attempt to address this gap through (1) providing a review of cases of teaching collaboration as a part of BIM tertiary education at universities around the world, and (2) identifying, synthesising and putting on display the best practices.

2 Literature Review

2.1 BIM: The crucial role of collaboration

There is a consensus in the industry that BIM is a useful tool, and as such, its wider adoption in the industry is needed. The creation of a BIM model is, however, a multidisciplinary activity that requires effective collaboration and information exchange between all stakeholders (Merschbrock et al., 2018). Collaboration for the construction context is defined as “a non-adversarial team-based environment, where through the early involvement of key members and the use of the correct contract, everyone understands and respects the input of others and their role and responsibilities.” (Hughes et al., 2012)

Implementing BIM in the absence of effective collaboration is described as merely ‘scratching the surface.’ (Mignone et al., 2016). The challenge of making multiple disciplines and organisations collaborate with each other is a major impediment to harnessing the potentials of BIM. And problems facing BIM-enabled projects in managing collaboration and corresponding remedial solutions have become an active field of research (Merschbrock et al., 2018), and a wide range of factors are identified as the enablers of collaboration in BIM-enabled projects (Mignone et al., 2016). From a contractual perspective, Olatunji (2011) argued that traditional notions of responsibility and the conventional legal structure dominating BIM-enabled project hinder collaboration. A wide range of studies, however, attempted to enhance collaboration through the use of more effective collaboration technologies (Merschbrock et al., 2018). Yet, according to (Emmitt and Ruikar, 2013) “It is therefore not so much a technological issue as it is a human behavior one.” With this in mind, many investigators including (Becerik-Gerber et al., 2012) suggested the incorporation of the principles of collaboration into tertiary BIM education programs. This insight was acknowledged by the world of practice, where a lack of training and BIM skill in university graduates is still treated as a major limitation to BIM implementation. This resulted in attempts towards including collaboration within the tertiary BIM education is several institutions.

2.2 Collaboration in tertiary BIM education

Communication, trust, good faith, and mutual support are prerequisites of collaboration. These underscore the interdependence of systems, culture, and individual attitudes in enabling collaboration in the workplace (Merschbrock et al., 2018). Oraee et al. (2017) argued that factors such as the ‘Task’—the nature of the work being performed—and ‘Actors’—the skills and knowledge of the individuals involved—are indispensable to effective collaboration in BIM-enabled projects. These insights are echoed by studies asserting that conflicts encountered during collaboration largely stem from interactions between competing priorities of individual, project and organisation. These further highlight the crucial role of individuals in establishing collaboration (Mignone et al., 2016, Merschbrock et al., 2018).

Effective collaboration, therefore, is rooted in an understanding of the role of other disciplines and an ability to manage interactions between different disciplines (Merschbrock et al., 2018). This is independent of the technical knowledge and emphasises the need for including teamwork and collaboration KSAs among the learning outcome for tertiary BIM education (Adamu and Thorpe, 2016, Becerik-Gerber et al., 2012).
3 Research Methods

The objectives of the present study necessitate identifying the concepts, reviewing the related literature and analysing the studies related to the topic. All these objectives are deemed in accordance with the capabilities of the systematic review method. For this analysis, a 3-staged systematic review approach is considered, as illustrated in Figure 1. This entails the process of identifying: (1) studies discussing BIM education, (2) studies that describe BIM education in tertiary education, (3) studies that discuss collaboration in BIM education at tertiary education.

The data are obtained by running a keyword search on the Scopus database, given its wider coverage and quick indexing (Oraee et al., 2017). The search process starts by identifying relevant keywords and targeting journal articles published in journals since 2003, when the first BIM paper was published (Hosseini et al., 2018), with the keywords, as illustrated in Appendix A. The search process results in identifying a pool of 358 studies as of March 13th, 2018. These papers are then further qualitatively analysed upon satisfying the below criteria:

- They feature a case study of one or multiple courses taught in a tertiary education institution.
- The case study features the use or discussion of BIM in the course.
- The course involved team-based work or discussed collaboration more broadly.

In this stage, at least two research team members review all the 358 identified articles. One article is omitted, given that none of the members provides a reason for retaining the article. As a result, 63 relevant studies on BIM in tertiary education, in particular, are filtered out. In the final stage, these studies are fully read and analysed by at least two research team members, to identify the elements that contribute to the learning of collaboration KSAs by students (18 studies). Positive contributions are identified based on evaluations, or inferred based on the outcomes and limitations. The best practices among these are highlighted and discussed. The emphasis is on practices that are easily reproducible and contribute to the fundamental collaboration KSAs by the students.

4 Findings

The 18 papers identified as the now available literature on teaching collaboration in tertiary BIM education are tabulated in Appendix B. The content analysis of these studies reveals that current best practices can be presented under 4 broad categories and 12 subcategories, as illustrated in Table 1.

Table 1: The best practices in identified studies (see Appendix B for details of studies)

5 Discussions

5.1 Instructional approach

The instructional approach covers the method of delivery, the deliverables, the resources provided to students, and the interactions between them and their instructors. In selecting these, it is important to focus on whether the approach will give students an insight into the challenges and the conflicts associated with working collaboratively, and whether it will give them a framework within which to resolve those conflicts. It is not sufficient to organise students in a team, give them a task to perform and allow them to work on it. Instructional features must also highlight the reciprocal interactions between students’ technical skills and soft skills. The main dimensions related to instructional features are discussed below.

5.1.1 Project-based learning and task selection

As illustrated in Table 2, all 18 studies support Project Based Learning (PBL) and Team-Based Learning (TBL) as their primary instructional approach. Under PBL, students are assigned a task (single large project or a series of smaller projects) that is to be completed over the duration of the course. Collaboration learning is classified under Bloom’s taxonomy, and therefore, the experiential learning model can be an appropriate method to teach collaboration skills (Bloom et al., 1964). In the context of collaboration education, however, this means that students need to possess the required domain knowledge necessary to complete the project (this is discussed further in subsection 4.2.1). The complexity and the information requirements of the task, therefore, play a crucial role. This was highlighted by Solnosky et al. (2015). They argue that the course outcomes are best when the task assigned to students has the following characteristics:

- The case comes from a live project with a professionally produced request for proposal.
- The students do not have access to completed design and are required to generate alternatives for the design.
- The case requires unique and interdependent deliverables from all team members.

Due to the volume of effort required to effectively complete such a task, many universities opt to include it as a capstone project, typically as a standalone final project (Zhang et al., 2017). Students that engaged with a collaborative task as a part of regular coursework suggested reduced success in collaboration, including challenges with scheduling and time management between competing priorities (Ghosh et al., 2015, Wang and Leite, \[220.\]
2014, Wu and Luo, 2016). The coursework based exercises also require less complex projects and rigidly-defined scope of work in the interest of time.

5.1.2 Industry mentors

In the PBL methodology, the role of instructors is one of guiding and facilitating the process, rather than teaching the domain knowledge. When students are simulating a design or planning exercise in a BIM-enabled environment they need access to mentors that can guide them on both the technical and workflow related challenges. Mentors that work in the industry or are otherwise actively engaged in workplace practices can ground the process in the current standard and even help the students exceed those standards (Mathews, 2013). Industry mentors also increase student engagement and increase their confidence in their practical skills.

5.1.3 Standards, tools, and documentation

Collaboration relies on all participants having similar expectations of communications and workflow, and as such, following a standardised framework can be a remedial solution. As an example, Adamu and Thorpe (2016) emphasise the importance of training graduates to be versed with the BS1192 series. Collaboration tools for BIM include both technologies, like data sharing platforms, and management tools like the Dependency Structure Matrix (Pektas, 2014). Mandating the use of an organisational tool like the DSM helps students understand how their tasks fit into the overall building life cycle. The deliverables should also include documentation of the collaboration and the tools used. This can take the form of meeting minutes (Wang and Leite, 2014), progress reports (Wu and Luo, 2016), regular posts on a discussion board (Mathews, 2013), or simply giving access to the instructor to the work-in-progress files (Zhao et al., 2015). This type of documentation encourages cooperation.

5.1.4 Team building exercises

A formal team building process prior to the commencement of the project supports the building of trust and group identity. Team building exercises are essentially structured interactions where team members can introduce themselves, express their roles and preferences and understand the preferences of their team (Korsgaard et al., 2005). As an example, McCuen and Pober (2016) began their project work with an 8-hour intensive introductory session, where teams were assigned, introduced through team building exercises, and then asked to work together to set standards to share information and define platforms for communication and co-ordination. The students identified this as one of the critical factors to project success.

5.1.5 Self-analysis tools

Alongside group processing, individual students must also be supported in reflecting on their own collaborative behaviours. Self-analysis tools like an emotional intelligence test (Zhao et al., 2015) or reflective assignments (Mathews, 2013) do not directly contribute to the deliverable in the short term, but in the long term are important to adjust behaviour and improve overall impacts (Coleman and Voronov, 2003). These tools can also be used to support underperforming team members and address their individual challenges.

5.2 Prerequisites

In this context, prerequisites focus on the competencies that students need, prior to starting a collaborative BIM project.

5.2.1 Complementary construction knowledge

Teaching collaboration is only effective when complementary domain knowledge exists in a team, namely, every member of the team has a unique role and expertise on some dimension of construction knowledge. The exception to this is when students are collaborating on a cross course project, as the one attempted by Wu and Luo (2016). In this case, students on each project team were learning a different set of technical knowledge and applying it to the collaborative group project. The primary challenge, in this case, was logistics, for both the students and instructors.

5.2.2 Familiarity with BIM tools

As all participants will be expected to prepare some elements of a BIM model, it is possible to introduce BIM alongside collaborative coursework, however, better learning outcomes are seen when participants already have a level of familiarity with BIM (Mathews, 2013). Bozoglu (2016) addressed this by organising a workshop on the basics of BIM with an industry partner at the start of the coursework. Subsequently, students will engage in co-learning and support team members with lower skills (Becerik-Gerber et al., 2012).

5.3 Marking and evaluation

The marking and evaluation practices suggested here are those used in previous studies in order to enhance the quality of output, make students accountable to each other and the task.

5.3.1 Readiness evaluation

Prior to starting the task, instructors can administer a ‘Readiness Assessment Test’ (RAT) to both individuals and the team (Zhang et al., 2018). The purpose is to evaluate the understanding of the task scope, context, and team characteristics. This evaluation ensures that all participants have understood all the key elements of their task equally.

5.3.3 Peer Evaluation

Peer evaluation helps instructors assess if individuals contribute to their tasks and pay attention to peer accountability. Being in a group with a ‘social loafer’ is a universal experience. When individual contributions in a group project are not apparent, certain individuals will not contribute to the project expecting that other team members will compensate for their lack of productivity. This phenomenon is minimised when individuals are accountable to their peers and have tangible negative consequences to a lack of contribution. Peer evaluation can take the form of a standardised tool like surveys (Solonsky et al., 2015, Becerik-Gerber et al., 2012).

5.4 Feedback

Data collection is necessary for modifying the course structure on multiple iterations, as well as, complying with industry requirements. This can be achieved by integrating feedback from both the industry and students.

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5.4.1 Industry jurors

According to PBL principles, the outcome of a student project should be shared with the professional community for feedback, as well as, to share any insight offered by the findings of the project (Leite, 2016). Inviting jurors from the industry to comment on students’ projects is the best approach towards these goals, resulting in increasing students’ engagement, and giving them an opportunity to network with potential future employers (Solnoisky et al., 2014).

5.4.2 Student feedback

Most university systems already incorporate student feedback within the curriculum building process. For collaboration teaching based on PBL, however, the importance increases as every iteration of the course will be unique with specific challenges. Student feedback helps identify these challenges in order to tackle with them.

6 Conclusion

This study is unique as it is the first one providing a review of available studies on teaching collaboration within BIM education. This is through identifying 12 best practices in the realm of BIM collaboration education. This is deemed the contribution of the study to the body of knowledge: (1) synthesising the lessons learned and best practices of teaching collaboration in BIM education, as attempted around the world, (2) extraction and putting in display the major issues and challenges of such attempts. The best practices identified here reveal the necessity of ensuring that students see the collaboration process as positively contributing to the quality of their output; the process must be managed to avoid students deeming the act of working in a team as inherently negative and inconvenience. The best practices provided here are invaluable in addressing this objective. The biggest barrier to teamwork in the learning process is found to be the conflict between collaboration learning outcomes and the technical deliverables of the project. In the absence of appropriate guidance and management, the deliverables interfere with the collaboration learning and prevent the students from taking advantage of the process. Another major issue is a lack of clarity on what constitutes collaboration KSAs for individuals.

Discussion of such topics will also be invaluable for tertiary education institutions and policy makers in practical terms. That is, the best practices introduced here can be replicated to enhance the quality of project-based learning within construction-related fields. Educators and policy maker can draw upon the experiences discussed here in designing their training programs, and learn from the past to come up with remedial solutions to deal with the challenges discussed here.

There has been an attempt in this paper to frame those KSAs in terms of collaboration tools, standards, and self-awareness. This is, however, limited and warrants further investigation to identify what teachable characteristics an effective collaborator in the construction industry requires. The research is also limited, largely due to its reliance on published papers, the lack of consistency in the type of data available across papers, and the limited number of papers from universities outside the USA. The papers reviewed are all in English and may exclude relevant research in other languages. This limits the generalisability of the findings, and the effectiveness of some of these practices may be affected by cultural differences. The assessment of best practices is partly subjective. Further research can include a comparative study between collaboration learning outcomes across universities where some of these practices are implemented versus students not trained in collaboration through these techniques. As discussed earlier, more research is also needed to identify the key collaboration KSAs in BIM.

7 References

Abstract:

The introduction of Building Information Modelling (BIM) into the Architecture, Engineering and Construction industry (AEC) has completely revolutionized how we design and construct buildings. BIM shows significant positive changes for the consulting industry in terms of reducing errors, understanding buildings, realistic visualization, clash detection amongst other remarkable features. However, BIM is an ongoing course of complex processes and it is important that users are kept in the loop of new concepts, processes and workflows. Universities, the world over are making concerted efforts to introduce and implement BIM education for their built environment courses as it has become a component of a professionals practical training. However, it is necessary to determine at what level BIM education is being implemented at educational institutions. This research explores how South African built environment schools have implemented BIM in their teaching syllabus and level of implementation. Data was collected using questionnaires from representatives at built environment schools or departments in the public universities. Findings reveal that there is some usage of 2D and 3D CAD in design modules at some universities. However results suggest very little implementation of BIM methods and processes in many universities. This research will be useful for the AEC industry in terms of judging the level of education in the BIM spectrum and can assist with future training of professionals, regarding BIM.

Keywords:

BIM, AEC, Education, Implementation, South Africa

1 Introduction

In the past decade, Building Information Modelling (BIM) has become a key driver in the design and execution of constructing buildings across the globe. Now, more than ever, BIM is revolutionizing how architects, engineers, project managers, quantity surveyors and other built environment professionals conceptualize, design, document and execute the construction of buildings. BIM is no longer a catch phrase for impressive software but rather a complex system of design and documentation that allows for reduction in error, complexity in design, visualization, virtual building and other cost and time saving benefits. As BIM leaves its infancy behind, the training of specialist consultants in the arena of BIM is becoming imminent. Globally, BIM has “caught on” in the Architecture, Engineering and Construction (AEC) industry and consulting firms expect a high level of skill from candidates entering the work force. An expectation of a candidate new to the built environment job market hinges heavily on abilities that are inclusive of a BIM skill set, however the industry believes the acquisition of these specialist skills remains the responsibility of academic institutions. It is in this sentiment that this research explores how universities are implementing BIM into their courses.

Academic Institutions are focusing resources into the development of BIM education for their students in a fast-paced approach. New laboratories are being set up at universities and the construction of buildings. BIM is no longer a catch phrase for impressive software but rather a complex system of design and documentation that allows for reduction in error, complexity in design, visualization, virtual building and other cost and time saving benefits. As BIM leaves its infancy behind, the training of specialist consultants in the arena of BIM is becoming imminent. Globally, BIM has “caught on” in the Architecture, Engineering and Construction (AEC) industry and consulting firms expect a high level of skill from candidates entering the work force. An expectation of a candidate new to the built environment job market hinges heavily on abilities that are inclusive of a BIM skill set, however the industry believes the acquisition of these specialist skills remains the responsibility of academic institutions. It is in this sentiment that this research explores how universities are implementing BIM into their courses.
across the world, implementing high-end hardware, the latest BIM software and highly trained staff to bridge the gap in the skills set upon graduation of a candidate. It is evident from enquiry, that universities require a basic understanding and ability of use in BIM, however the question remains pending, at what level in the BIM spectrum is the training implemented and how are schools relating it to the Level of Development (LOD) in the BIM field?

This research makes use of a mixed method approach of primary quantitative data gathering techniques and qualitative interview based, focused questionnaires and a secondary source of literature to explore the usage of BIM implementation and the Level of Development (LOD) at higher learning institutions in South Africa.

2 Literature Review

2.1 The evolution and concept of Building Information Modelling (BIM)

As the world moves towards a fourth industrial revolution, technology is proceeding at a rapid pace in all continuums. The Architecture, Engineering and Construction (AEC) disciplines are similarly not excluded from this occurrence. The digital age has changed how buildings are being designed, documented and executed, smarter than ever, through the use of Building Information Modelling (BIM). BIM had its first introduction in 1957, through the use of Computer Aided Machining (CAM) software from which it developed further into Computer Aided Design/Drafting (CAD) in the early 60’s of which was the initial stepping stones of BIM (Goubau, 2012).

Although CAD had developed and was being adopted, it was fundamentally flawed in the sense that traditional CAD represented lines and arc’s similar to that of a drawing board, the benefits were seemingly not significant to consultants, contractors and clients (Kensek and Noble, 2014, p.xxiii). Similarly, Ibrahim (2006, p.265) reinstates that CAD was a replacement of the drawing board and meant that the only challenge was the training for use of the application, Ibrahim further re-establishes that unlike CAD, BIM is thinking of the building process and not about the process of drafting (Ibrahim, 2006). From the author’s opinions on the differentiation of CAD and BIM, it is clear BIM is more than just a tool for drawing but includes depth of information that can be useful for all stake holders on a project.

By the 1980’s a major commotion occurred in the AEC industry by means of 3D CAD. BIM became a disruptor in the CAD industry as it brought along with it a new way of thinking about product and building design (Quirk and Bergin, 2017). Consultants had to now think more intensely about the building in terms of size, geometry, information of materials, implementation etc. According to Gordon et al (2006, p.38) the biggest goal BIM sought to achieve was an intelligent information database that was common to all that worked on the project which allowed for unified and progressive approach that was ultimately handed over to the building owners and facilities managers. Azhar (2011, p.242) similarly elucidates that BIM can be understood to include all disciplines, aspects and systems of a building into a single virtual model which allows all stake holders to collaborate more efficiently than traditional methods. It is imperative to understand that BIM is a process of collaboration for a common goal and requires depth of information that is synthesized in one central file, it is this central source that ultimately defines the power of the BIM concept.

In the present day, BIM is taking over the AEC industry and consulting companies, contractors, clients and facilities managers are seeing the benefits of a central database for their buildings (Azhar, 2011, p.243; Eastman et al., 2011, p.1). The demand for BIM is becoming more evident in recent years and governments and multi-national companies becoming the forerunners for implementation of BIM on their projects (HM Government, 2012). As the demand for BIM grows, the question of competent users come to surface, how are universities preparing their students for the working world and the complexities of BIM systems? In the next section, the authors examine literature that has explored the implementation of BIM into curricular and how effective this implementation has been to prepare graduates for the challenges of BIM.

2.2 The implementation of BIM in University Curricula

As BIM becomes more popular amongst stakeholders in a building project, an immense amount of focus is set on training on BIM platforms. It is important to note that BIM took an upward curve from around 2007 with respects to a conversion from CAD to BIM at universities (Mandhar et al, 2013, p.4). Similarly, Abdirad and Dossick (2016, p.255) tracks the progress of implementation of BIM in curricula from 2007 to 2015 and elucidates a chronologic development of BIM in curricula. According to Abdirad and Dossick (2016, p.255) from 2007, universities focused on moving from CAD to BIM, then focused on the integration of BIM into syllabi thereafter developing into integration of BIM across construction related courses and at present pedagogical strategies to improve the educational outcomes of BIM. Although BIM has had an intriguingly sharp incline of adoption and implementation into construction education, a few outstanding problems persist in teaching and learning of BIM. The literature suggests three issues that are inherently troubling and the authors of this particular research feel it is a worthy mention.

Through integration of BIM into the syllabi, both positive and negative effects are observed by various authors. According to Boeykens et al (2013) the issue of mind-set in architectural design is a critical issue. According to Mandhar et al. (2013) the issue of mind-set in architectural design is a critical issue. In architectural design studios it is observed that educators themselves view BIM as just another CAD software which students are expected to learn in their own time and reinforces the fact that it affects creativity. It is evident from the author’s views on BIM adoption in curricula, there exists a major mind-set issue in the use, training and adoption of BIM.

Although mind-set in the adoption of BIM is a critical issue, the competency of teaching staff is another major issue observed in built environment schools. Mandhar and Mandhar (2013) states that a critical issue in the training of graduates in BIM is the lack of competent teaching staff. Similarly, Bervald, (2008) elucidates the current nature of teaching staff; “Currently, professors are more comfortable critiquing physical models and two dimensional drawings such as plans, sections and elevations than a 3- dimensional digital model. While this is understandable given the tools that existed at the time of their training, it can be problematic.” It is from the various authors opinions we are able to paint a picture of the issue of staff that are not 100% trained in BIM. However, what strategies are universities implementing to include BIM into the curriculum so that it becomes a holistic exercise for both students and the teaching faculty?

BIM implementation in university syllabi is fast becoming a reality and universitites are making it a priority to produce graduates that are competent and ready for industry. Current literature suggests that there is a high implementation rate in most countries but
they are still experiencing issues of integration with other courses. According to Barison and Santos (2010) there exists three approaches for the integration of BIM into curricula namely; Single Course: Where institutions are implementing BIM, but only in one course e.g. Architecture, Interdisciplinary: Where institutions are implementing BIM with collaboration of other disciplines but at the same institution and Distance Collaboration: Where institutions are implementing BIM with two or more other Institutions creating a collaboration over distance. From Barison and Santos, the three major methods of integration are made clear, however various studies suggest that standalone BIM courses are not as powerful as integrated BIM course and does not promote long-term learning, furthermore due to students only implementing the process for that specific course they do not retain the skill set and feel it difficult to reapply it to other courses (Ghosh et al., 2013, Gier, 2008, Cleverenger et al., 2010 as cited in Abdirad and Dossick, 2016, p.258).

There issues of collaboration that exist are mainly related to the cross disciplinary aspects of working at a university setting. Although as difficult as the setting may be, many countries and institutions are determined to make it work and learn from the issues that exist or may arise. According to Mandhar and Mandhar (2013) BIM implementation in curricula in the United Kingdom is driven by the Royal Institute of British Architects, The Government and Architectural Practices to fully prepare graduates for the working world. Similarly, USA, Australia, the Scandinavian Region, Singapore, China, South Korea and Brazil are pushing the same agenda through the various stakeholders (Kolaric et al., 2017). It is clear that with support from all stakeholders, universities will be able to implement BIM faster and better than without the necessary support. Through the review of various literature, it is becoming evident that BIM implementation in university curricular of AEC courses is becoming top priority. The evident problems of mind-set, knowledgeable staff and integration of BIM across courses can be seen as early teething problems and can be resolved through proper approaches. It is evident that the first world countries have been increasing the gap in BIM implementation, however what strategies are being implemented in the BRICS countries to implement BIM in the processes? The next section of this review investigates the implementation of BIM in the BRICS countries to form a background to the level of implementation of BIM in educational institutions.

2.3 The implementation of BIM in BRICS Countries University Curricula

The BRICS countries consist of Brazil, Russia, India, China and South Africa and is an association show the five major developing economies. The BRICS countries show much promise in terms of development and an investigation into the level of adoption of BIM is critically important for this study. This section gives a brief overview of the level each of the BRICS currently implements. Brazil is currently in its infancy with respect to BIM, it still currently has no national frameworks that promote the use of BIM or guidelines for the implementation of BIM in educational institutions (Kassem, 2016). However, The Brazilian Government has sought the services of Mohammad Kassem to assist with the framework and implementation of BIM in Brazil (Cousins, 2014). Russia has learnt from the UK’s strategy of BIM implementation from which it used a few projects to gain its footing in the BIM industry, furthermore the Russian Government has implemented frameworks to instal the use of BIM for construction projects (Mills, 2016). In India, the AEC industry is the second largest industry after the Agriculture industry (Amaranath, 2017). BIM is being highly implemented in India, however it is still in its “experimentation” stage and India unfortunately does not have a Framework set up by government for BIM implementation (Ahuja et al., 2016). A well-known fact about China is their front-running in digital technology, consequently the uptake of BIM implementation has been fast paced and software giant Autodesk has set up many programmes in China for the development and implementation of BIM (LITENG and Jun Kim, 2010, p.412). The Chinese government has also implemented BIM for use on big projects, which also reveals the they are moving in the right direction with regards to BIM implementation (O’Neil, 2017). BIM is also being heavily implemented into AEC education in China and new strategies and pedagogies are being applied (Zhang et al, 2016). According to Harris (2016) the uptake and implementation of BIM in the AEC industry of South Africa has been very slow. Although many institutions exist and promote BIM, the industry has not taken to the concept as quickly as other countries.

2.4 BIM maturity and Level of Development

To fully understand the BIM process, one must interact with two major concepts in the BIM spectrum, namely: BIM Maturity and Level of Development (LOD). In this section, the concepts are explained to create a knowledge base to be implemented in the empirical study.

**BIM Maturity**

The BIM Maturity level model was developed by Bew and Richards in 2008 and has become the UK’s main component for an implementation strategy (Sucar, 2015 as cited in Dakhil and Underwood, 2015, p.236). The BIM maturity model has four levels in which maturity is illustrated and judged upon, the following figure graphically represents the maturity levels:


According to Dakhil and Underwood (2015, p.236) and Balu (2017) the following is an explanation of the maturity levels:

**BIM Level 0:** Is termed as an unmanaged CAD system which represents lines and text but not depth of information. It is also termed the digital drawing board.

**BIM Level 1:** Is termed as a managed 2D and 3D CAD system with standardized formats and structures, furthermore BIM level 1 is considered the “Lonely BIM” as the model is not shared with other team members, the purpose of it is mostly for conceptual work.

**BIM Level 2:** Is termed as a managed 3D model with other parametric data, but each discipline creates a separate model which will be consolidated into one model but will not lose their integrity or identity.

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BIM Level 3: Is termed as a highly managed collaborative project model which is referred to as an integrated model. The model is handled through a collaborative server for use by all team members in real time. BIM level 3 is still in development and has still not attained the goals it has set out.

It is clear from the literature that the BIM maturity levels are an important step for the BIM industry, the BIM maturity level model aims to unify the work processes and describe to its users the stage that they currently fall into and what they would need to accomplish to rise to the next level.

Level of Development (LOD)

Although the BIM Maturity model has a broad perspective of the use of BIM, it also incorporates model based development which is an important concept, to this we refer to Level of Development (LOD). According to Adams (2017) the LOD is the level at which a part of the model, or the model itself has been developed with regards to the information it carries. Adams (2017) defines the LOD below:

LOD 100: The basic Form.
LOD 200: Generic Form, Approximate size, shape and location.
LOD 300: Specific shape, size and location.
LOD 350: Actual model of product including its shape, size and location.
LOD 400: Similar to LOD 350 but including fixing, assembly details and information.

The level of development however does not flow from stage to stage, at times a model will contain other models which are at different LOD’s (Alderton, 2017). It is of great importance to understand the LOD concept, especially for students at tertiary institutions using BIM. The critical development of a building that LOD provides actually assists designers to make decisions in a step by step process. This research will further investigate the LOD at built environment schools in South Africa to judge the level at which BIM is being implemented.

3 Research Methodology

This research made use of a mixed method approach of qualitative and quantitative data collection methods from which rich data was extrapolated to reveal significant findings. South Africa has 13 Universities which offer some type of Built Environment course, however the primary data was collected from 9 universities in South Africa due to time constraints. The study focused on the departments that most used the BIM philosophy in their teaching strategies, these departments were the Architecture, Civil Engineering and Construction Project Management programmes.

The study made use of a questionnaire which was both quantitative to gather statistical data and qualitative to determine what the issues were with the implementation of BIM. The questionnaire thus, was structured in its first part as a formal questionnaire to gather data and qualitative to determine what the issues were with the implementation of BIM. The questions were grouped and a bar chart implemented for interpretation. The findings for this research will begin with the statistical data collected to frame the context in which the South African Schools of the built environment implement BIM. Since statistical significance was not a requirement for this study, output from the analysis of the data was more qualitative with the quantitative output being frequencies of occurrence or presence of evidence of implementation of BIM.

4 Findings and Discussion

The findings for this research will begin with the statistical data collected to frame the context in which the South African Schools of the built environment implement BIM. The questions were grouped and a bar chart implemented for interpretation. The discussion will then lead onto the qualitative questionnaires which will explain the issues surrounding implementation of BIM at South African built environment schools. The following sections give an insight into the various findings of the research.

4.1 Academic Institutions and Departments included in the study

The first approach to the research was to quantify the data sets according to the Academic Institution and Department the research was conducted in. The following bar graph gives insight to this statistical data:

![Figure 2: Number of Universities included in the study and Departments](image)

From the data presented, 9 Universities participated in the study, from the 9 Universities four major departments namely the Built Environment, Civil Engineering, Architecture and Construction Management & Quantity surveying faculties responded to the questionnaire. The next data set gives an indication of how BIM is implemented into the syllabus.

4.2 BIM Implementation

The second part of the study directed questions towards the actual implementation of BIM within the departments or courses, furthermore questions were asked about the department’s intentions to introduce BIM, the specialist staff that were employed to teach BIM and the current undertaking of BIM research within the department. The following graph gives insight into the levels of implementation of the various questions that were put forward to faculty staff:
From the data presented in figure 3, the researchers started the discussion of BIM offering in the department and if it was a compulsory requirement. According to the data presented, 10 respondents noted that departments they teach at, don’t offer a BIM course per se, however, 3 respondents noted that the department does offer some sort of BIM course and 1 respondent noted that they were unsure if the department indeed offered a BIM course. Similarly, respondents answered to the question of BIM being compulsory in the exact same fashion. At this point, the researchers noted that the faculties of the Built environment were not necessarily implementing BIM as a philosophy to strengthen their exit outcome; however, it is noted also a small amount of implementation is taking place formally. When asked about the department’s plans to introduce BIM into their courses, 3 respondents noted that they have not discussed strategies to implement BIM, 4 respondents noted that they have had discussions for BIM implementation and 7 respondents were unsure if BIM was to be implemented in future. The results of this specific question are worrying in the sense of an implementation strategy. If the current approach continues, South Africa will remain behind both in the BRICS consortium and the world at large with regards to the BIM philosophy.

The researchers further went on to specifically question the courses which included BIM and those that had a blended BIM implementation. It was discovered that 10 of the respondents answered with a “NO” to BIM being an elective course, 3 as “YES” to BIM being an elective and 1 respondent was unsure if a specific BIM module existed. When asked about blended BIM into courses, 6 respondents replied as unsure. The data presented here again is a cause for concern as it directly indicates the lack of implementation of a BIM course or blended learning. As compare to the other BRICS countries, South Africa is still lagging behind the pack in terms of BIM implementation at higher learning institutions.

As a closing on implementation of BIM at the faculties, the researchers posed two very important questions to the respondents, firstly the respondents were asked if a trained BIM expert was indeed teaching the BIM philosophy to students. A total of 9 respondents indicated that a BIM expert was not presently teaching at the department, 3 of the respondents noted that they did have a BIM expert teaching their BIM course and 2 respondents were unsure if there was a BIM expert presently teaching the BIM philosophy.

From the data gathered, significant deductions can be gathered about the state of BIM implementation at Higher Learning Institutions in South Africa, these conclusions will be further discussed at the conclusion section of this research. In the next section the researchers aimed at investigating which year of study BIM is being implemented and at what level of development (LOD) is being implemented.

### 4.3 Year level of BIM implementation

The researchers decided that it would be beneficial to the research if they knew the year levels in which BIM was implemented to complete the holistic picture of discovering what the implementation levels of BIM were in the higher learning institutions in South Africa. The following graph illustrates the years in which BIM is introduced and the level of competency students have and the end of the course.

![Year Level of Implementation](image)

The data presented in figure 4 is representative of the different years in which BIM is implemented. It must be noted that there are overlaps in faculties that implement the courses many times over the course of study. However, the research points towards the second year of study being the crucial year in which BIM is being implemented. This data is significant as it now paints a picture of exactly when in a student will get to grips with the BIM philosophy. The respondents also noted that in the first year of study, fundamentals are taught to students to prepare them for the second year of advancing their
studies in BIM. The third and fourth years were noted to be an advancement of the skill learnt in second year and the masters year of study, was only being implemented at one institution, that being the architecture course at the Tshwane University of Technology (TUT). It must be further noted that not all institutions offer advance BIM techniques due to the lack of supporting staff and the workload of the actual core course takes precedent.

![Expertise at Year Level](image)

Figure 5: Expertise in use of BIM at the difference year levels

One other factor that is important to note is the expertise level of students that are introduced to and taught BIM at Higher Learning Institutions. It is noted that on average, students have a basic understanding of BIM in their first year, although not a large number, but a significant number to deduce such. Through the survey, it has been discovered that student’s skills and abilities in 3D modelling pick up pace at the second year of study and their skills become extensive as they move up to higher years.

4.4 Level of Development

The Level of Development (LOD) is an important part of the BIM Philosophy and it vital that it is implemented at Schools of the Built Environment so that the idea of staging becomes apparent to students early of in their development of both BIM and Projects skills. The researchers implemented a small survey to identify if faculties were indeed teaching with the LOD’s. The graph below illustrates the findings of this study:

![LOD Implementation Level](image)

Figure 6: Implementation of LOD’s

With reference to the above graph, it is evident that Higher Learning Institutions are heavily implementing the LOD 1 system. It is a good sign that some effort is made to implement LOD’s however working only in a basic LOD is worrying at an exit level. Only one institution, TUT, has implemented the LOD system all through to LOD 5. The response from most institutions were none, partly because the lecturers did not understand the LOD system or felt that it was not important to implement it. Due to the lack of results from this particular survey, a holistic view cannot be truly formed on the implementation of the LOD system and could be researched further at Built Environment Faculties in South Africa.

4.5 Philosophy relating to the implementation of BIM

The final question posed to the respondents was an open-ended question. Respondents were asked what was the Departments Philosophy on BIM implementation? The responses made for an interesting set of data. 20% of all the academics interviewed responded in the negative, giving an account of them being unaware of any philosophy being put forward for the implementation of BIM. Furthermore, one respondent stated: “In academic circles in South Africa, BIM is a very new concept. The BIM implementation has not been thoroughly discussed in our department. The university body might have discussed it but I am not aware of that. Furthermore, I have not read any philosophy in relation to BIM either in the university, faculty or department”. It is necessary to unravel this particular response as it doesn’t come as something new, not only at South African Universities, but internationally as well. BIM in academia is fairly new, thus the issue surrounding its implementation is also challenging.

The second major discussion point, which was also noted in the statistical research, is the ability of the lecturers and their expertise to teach with a BIM Philosophy. The issue of BIM skills has become contentious amongst academics in the Built Environment schools, partly because they were trained to be an architect, a civil engineer or a project manager, not a BIM expert. One response was: “We are geared to the implementation of BIM. However, fellow lecturers need training themselves in order to understand the full potential of BIM”. It is evident that lecturers are embracing the new, however, the issue of being trained is a big one.

All the respondents interviewed, responded positively to why a BIM Philosophy should be implemented. It is noted in many instances, that the respondents believed that BIM technology is time saving and cost effective and should be implemented, however many respondents subjugated BIM as a “TOOL” and not the main focus of the course. One respondent shared his account: “BIM skills are necessary for the employability of graduates. We do not find much pedagogical value in teaching BIM but consider it a necessary component of their education”. It is understandable why the academics believe strongly as BIM being a tool and not the core focus of the course of study.

The fourth major discussion points amongst all respondents was the issue of employability. All the academics interviewed were confident that students with a high level of skill in BIM, were more employable. The issue of employability is also a contentious one, students are somewhat prepared as they leave universities as graduates however is the skills sufficient to “hit the road, running”? According to the quantitative data collected for this research, it is evident that students are not fully prepared in terms of being BIM proficient.
5 Conclusion and Further Research

The study set out to establish at what level BIM was being implemented at Higher Institutions of learning in South Africa. Further, the study set out to determine the level of development that universities are able to reach in BIM teaching. It is crucial to understand that through this research it was discovered that the implementation of BIM at the institutions are incredibly low, most of the time a lack of knowledge of basic BIM concepts was not understood by the participants. It is also noted that a BIM philosophy was not discussed in detail at the various universities, partially because BIM has not been implemented at a governmental level as yet.

The implementation of the Level of Development (LOD) framework is also a major concern, through the research it has been discovered that a very large percentage of universities only apply the LOD Framework at level 1. By the application of BIM at such a basic level, students are not as well prepared for the working world as it has been imagined. The researchers find it incumbent that the government start with a BIM strategy for the country which must trickle down into the university syllabi. Although BIM is not implemented at a national level, the universities could make concerted efforts to uplift BIM skills of their graduates.

The most important takeaway problem from this research is the skills training for existing lecturers, time and time again research points back to lack of training of staff. It is recommended that faculties of the built environment professions cross pollinate ideas amongst themselves in order to form a BIM implementation strategy to produce graduates that possess a high level of skill in BIM.

Further research must delve into the detailed issues and challenges of BIM implementation and the causation of such slow progress. One of the other burning issues with the BIM philosophy is the integration with the core subjects of the course, further research into the challenges facing integration is vital to understand the complex nature of BIM incorporation into the syllabi.

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7 References


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Effects of BIM transaction attributes on the trust-based functional contracting in engineering, procurement and construction (EPC) contracts

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Abstract:
The adoption of the Building Information Modelling (BIM) has implications on asset specificity, behavioural uncertainty, and environmental uncertainty. These transaction attributes affect contract structure. Despite a trust-based functional contracting proposed to enhance BIM performance for engineering, procurement, and construction (EPC) projects, an understanding of how BIM transaction attributes influence the relationship between contract functions and inter-organizational trust in EPC contracts is imperative. Drawing upon theories related to transaction attributes, interorganizational trust, and functional contracting, we developed a series of propositions that shed light on the effects of BIM transaction attributes on the contract functions and inter-organizational trust in EPC projects. This study contributes to the knowledge development of trust-based functional contracting in BIM-enabled projects based on the EPC approach. It renders practical implications for the construction practitioners in devising an appropriate BIM-enabled EPC contracts to address the specific transaction attributes arising from BIM.

Keywords:
Asset specificity, behavioural uncertainty, building information modelling, contract functions, environmental uncertainty, EPC

1 Introduction

Using the Building Information Modelling (BIM) in construction projects requires a high level of trust in collaborative activities among project participants (Lee et al., 2018). Nevertheless, traditional formal contracts such as engineering, procurement, and construction (EPC) contracts, which are used to safeguard parties’ transaction by specifying what is and is not allowed in a transaction (Lui and Ngo, 2004), inhibit relational developments between contracting parties (Malhotra and Murnighan, 2002). Traditional contracting is grounded in the transactional contract law approach that does not recognize cooperative relationships (Williston and Lewis, 1920). Functional contracting is a contracting approach that foregrounds the balance of contract functions to achieve desired outcomes from the transactions. It enables harmonisation between the formal controls and relational attributes in EPC contracting (Lee et al., 2018). There are three common contract functions in formal contracts, namely contractual control, contractual coordination, and contingency adaptability (Quanji et al., 2016). The main purpose of contractual control is to ensure adherence to a desired behaviour and outcome (Benaroch et al., 2016). Examples of BIM-related contractual control include audit for conformance to BIM deliverables and stipulated damages for failure of delivering BIM. Contractual coordination, on the other hand, allows interfaces between the contracting
parties (Mellewigt et al., 2007). This includes procedures that outline the model developed in stages. Contractual coordination promotes an increase in planning, trust, and cooperative processes, allowing adjustments to be made for the benefit of both parties (Salbu, 1997). Contingency adaptability defines the unpredictable contingencies that must be specified and the relevant procedures to deal with them (Luo, 2002). It may include requirements to update the changes made to the works on the model and procedures responsible for them. The collective actions to deal with the changes enable parties to share information thereby improving relational development (Williams, 2005).

In our previous study (Lee et al., 2018), we developed a structural model that demonstrates how contract functions influence positive outcomes of inter-organizational trust to enhance BIM performance in EPC contracts. However, the previous study did not clearly discuss how BIM transaction attributes affect contract functions and inter-organizational trust in the structural model. Existing literature has shown that transaction attributes such as asset specificity and environmental and behavioural uncertainty significantly influence a contract structure. In the transaction cost economics (TCE) perspective, when asset specificity is high, additional safeguards are required to protect transaction-specific investments, resulting in certain forms of relationships, such as project partnering, strategic alliances, and joint ventures (Aertsen, 1993). When a firm-specified investment cannot be deployed for other uses, the contracting partner may take advantage of the situation and maximise their own benefits at the expense of the firm, and as a result, the firm must deal with higher risk (Williamson, 1985). The firm is then required to develop an adequate control to restrain partner opportunism and minimise perceived risks (Parkhe, 1993). When an environment is too complex or uncertain for all alternatives to be fully specified, such as the uncertainties experienced in a construction project, the scope of rational decision-making is limited, and the transaction cost tends to be higher. In this case, the Contractor tends to subcontract out a large portion of specialised work to reduce the uncertainties and gain maximum flexibility (Winch, 1989).

On the one hand, BIM may reduce project cost and project delivery time and increase the productivity and quality of a project (Azhar, 2011). On the other hand, BIM implementation requires additional transaction cost for the parties (Arensman and Ozbek, 2012) and interdisciplinary teams contributing to the model (Aschraft, 2008), and it generates significant uncertainty (Arensman and Ozbek, 2012). BIM influences asset specificity of a construction transaction as well as the behavioural and environmental uncertainties of a construction project. Such influences may vary depending on the nature of a contract structure. This raises a critical question about the relationship between contract functions and inter-organizational trust: how can BIM transaction attributes influence contractual control, contractual coordination, contingency adaptability, and inter-organizational trust in the context of the EPC approach?

In this discussion paper, we developed a series of propositions about how BIM transaction attributes, such as asset specificity and behavioural and environmental uncertainty, influence the relationship between the contract functions and inter-organizational trust in EPC projects. The influence of BIM transaction attributes on contract functions and inter-organizational trust is a new area and has not been previously studied by scholars. It requires further research attention as it holds implications for devising an effective contract for better governance of BIM-enabled EPC projects.

2 Theoretical Backgrounds

2.1 Nature of EPC contract structure

EPC contract delivery enables the project owner to enter into an agreement with a Contractor, who will form agreements with various subcontractors and suppliers to carry out all the aspects of design, procurement, construction, and commissioning of a project. It allows the owner to control a certain degree of the design, utilise specialised skills of an EPC Contractor in engaging complex projects and single point responsibility, where the Contractor is responsible for a default due to design/engineering, procurement, and construction (McNair, 2016a). If the owner would like to direct significant changes to the EPC Contractor extracts a significant price premium to carry out the variation works. Nevertheless, this is an expensive option for the owner. Under-design is not often detectable though it has to be reviewed by the owner, which results in latent recurrent operational or maintenance costs in the completed projects. Project owners must solely rely on the EPC Contractor’s firm for recovery of compensation if something goes wrong with the project (McNair, 2016b).

2.2 Asset Specificity of BIM

TCE is the most prominent perspective informing the optimal governance of a transaction. The TCE theory influences a contract structure based on the transaction cost and its attributes. To TCE, asset specificity is one of the most important properties of a transaction (Williamson, 1985). It involves specific investment by one party in customizing a product or service that cannot be deployed for alternative uses (Poppo et al., 2016). Transaction gains can be enhanced by investments in asset specificity (Perry, 1989). However, an increase in the specialization of an asset also means an increase in the transaction cost (Dyer, 1996). The five common types of asset specificity are the site, physical asset, human asset, dedicated asset (Williamson, 1983), and procedural asset specificity (Malone et al., 1987). Site specificity refers to specialization by proximity, which is used to economize inventory and transportation expense (Williamson, 1981). Site specificity is not notably influenced by BIM. The physical asset specificity is the capital investment in equipment that cannot be deployed for other uses (Dyer, 1997). If a Contractor is using a BIM-based contract only for a specific owner requirement and does not deploy BIM in other projects, the additional cost paid by the Contractor for the purchase and maintenance of the BIM tools (Walasek and Barszcz, 2017) is considered to be physical asset specificity for the Contractor. Human asset specificity refers to a firm’s specific investment in human training to deal with routines of works, environments, and teamwork through “learning-by-doing” (Williamson, 1985). Deploying BIM requires high human asset specificity, as a Contractor needs to provide his employees, as well as subcontractors/suppliers, with knowledge and training regarding the use of BIM (Sebastian, 2010). Likewise, the Contractor must appoint a BIM specialist, such as an information/model manager, who is an expert in the usage of BIM for developing and maintaining BIM in the projects where the Contractor is responsible for the design and build. Dedicated asset specificity is the huge investment made in anticipation of continuing business and is additional to the other three specific investment types. Given that BIM is mandated in some countries such as Singapore and the UK, Contractors may purchase BIM tools as a long-term investment. This early cessation of business would necessitate selling the product of such an investment at distress prices (Williamson, 2002). Lastly, procedural asset specificity is defined as the customization level of one party’s work processes to fulfill another’s requirements (Malone et al., 1987). When a Contractor is involved in developing and maintaining BIM, he must establish
workflows to deal with model development, model sharing, and the use of a model with project participants in contributing and using the model (Sebastian, 2010).

BIM

Figure 1. BIM asset specificity

BIM increases the investment of project participants in terms of physical asset specificity, as it requires additional investment (Arensman and Ozbek, 2012) in the purchase of the software and hardware, management and operation costs, the cost of appointing a model manager, and any other associated costs. It also involves higher human and procedural asset specificity, since it necessitates that construction firms train their staff to familiarise them with the usage and procedures involved to achieve the project deliverables required by the project owner. Therefore, it is asserted that an addendum to the professional scales of fees is necessary, and standard remuneration should be provided to project participants who are required to use BIM (Olatunji, 2011). Dedicated asset specificity, in this case, refers to small/medium size firms that invest large sums of money to adopt BIM to increase beneficial outputs and in the anticipation of continued business with the clients.

A higher level of asset specificity will increase parties’ motivation to create a repeatable exchange (Williamson, 1981). On the one hand, high asset specificity commonly requires explicitly formalized contractual obligations in order to reduce the loss to one party resulting from the other’s incomplete or inadequate performance. On the other hand, high asset specificity also requires an intensive tacit knowledge transfer between the parties. Since developing a high degree of asset specificity necessarily increases transaction costs, parties who engage in such transactions are more reliant on one another’s cooperation (Coff, 1993). As such, relational norms play a significant role in coordinating and facilitating knowledge exchange between parties. Figure 1 shows the asset specificities arising from the implementation of BIM.

2.3 Environmental Uncertainty

In construction projects, environmental uncertainty arises when the external elements of an exchange are unstable and unpredictable (Abdi and Aulakh, 2017). In a BIM working environment, project participants must necessarily share their design information through a CDE. Environmental uncertainty may arise due to non-compliant design, translation error, data misuse, intellectual property rights (IPR) and model ownership (Arensman and Ozbek, 2012) and unclear rights and responsibilities of project participants (Simonian and Korman, 2010). Since the exchange is contingent and dynamic, it places great demands on the parties to apply their bounded rationality to predict future events (Shervani et al., 2007) when devising the contingency adaptability terms in contracts.

2.4 Behavioural Uncertainty

Behavioural uncertainty comprises of the potential moral hazards arising from human behaviour. It entails ambiguities in inter-organizational relationships due to difficulties in accurately understanding the other party’s behaviours or measuring its performance through moral standards (Anderson and Gatignon, 1986: 15). Developing, using, and maintaining BIM may increase or reduce several behavioural uncertainties. On the one hand, all the data is shared in CDE, and thus is easily accessible by the project participants. This may increase the likelihood of project participants to use the data for their own interest (misuse the data). In lieu of this, BIM contract protocols clearly define the limitations of using the model by project participants (CPC, 2013). If the contract does not provide stricter control in reducing the behavioural uncertainty, the interests of the project participants may not be well-protected. Hence, behavioural uncertainty could be a potential threat to the use of BIM. On the other hand, BIM can reduce asymmetric information between the contracting parties, as it provides greater transparency and access to construction project information (Forsythe et al., 2015). Nevertheless, to unleash this benefit, extensive contractual coordination and contingency adaptability are required.

2.5 Functional Contracting

A recent review showed that contract research is moving away from a narrow focus on contract structure and its safeguarding functions towards a broader focus that highlights adaptation and coordination (Schepker et al., 2014). Emphasising on functional contracting enables contracting parties to focus on specific contract functions to succeed in their transaction (Schepker et al., 2014). Several studies have used functional contracting to examine the effects of interfirm collaboration. Wang et al (2017) examined the effects of contractual control, contractual coordination, and contingency adaptability on cooperative behaviour to determine whether prior interactions breed cooperation in construction projects. Similarly, Quanji et al. (2016) studied the influence of the three types of contractual functions on the obligatory and voluntary cooperation of the transaction partner.

2.6 Inter-organizational Trust

Several studies have revealed that contract functions can influence inter-organizational trust (Lumineau, 2017; Lumineau and Henderson, 2012). There are three types of inter-organizational trust, namely calculative trust, relational trust, and institutional trust. Inter-organizational trust and interpersonal trust are interrelated (Lee et al., 2018). Inter-organizational trust enables partners to exchange personal and share decision-making (interpersonal trust), which leads to improved performance (Zaher et al., 1998). Contract functions influence calculative and non-calculative trust (also known as relational trust) (Lumineau, 2017). Calkulative trust describes rational perspectives of a firm when it regards another firm’s actions clearly benefiting the transaction (Kadefors, 2004), whereas relational trust is commonly influenced by intuition and perceived notions (Finke and Taylor, 2013). More often than not, relational trust affects the sentiments, intuition, or hunch of individuals based on several categories which include gender, age, race, geographical origin, friendship, kinship, or belonging of the managers to the same alumni network or professional association (Lumineau, 2017). Contractual control enhances the calculative trust of a firm with regard to the other firm through contractual control clauses such as provisions that address intellectual property rights and model ownership and
define the obligations of parties to develop, use, and maintain the model, calculative trust of a firm with regard to the other firm can be enhanced. Contractual coordination, such as the provision that requires consistent model review meetings of project participants, increases the relational trust of contracting parties, as parties may share common project objectives via factors discussed above (gender, age, friendship etc.). Contingency adaptability provisions such as granting an extension of time for parties who experience technical data errors could potentially improve relational trust between the parties.

3 Discussion and Propositions Development

3.1 Asset Specificity

While BIM-enabled projects tend to be less expensive for owners due to the decrease in change orders and addition of value for the downstream consumers, BIM is expensive to be newly implemented by an EPC Contractor. This is because EPC Contractors are responsible for the design/engineering, procurement, construction, and handover of the completed facility to the project owner. The requirements of implementing a design using a high level of BIM that ensures interoperability among BIM tools involves appointing a model manager to maintain and control the model and training the employees to operate BIM, and this requires higher asset specificity. In addition, the return on investment analysis also shows that design fees will most likely increase for companies working with BIM. This is a result of the increase in workload occurring during the earlier phases of a project designed using collaborative tools (Walaseka and Barszcz, 2017). As such, an EPC Contractor would be loaded with the additional cost of using BIM if he has to appoint third-party design consultants or have in-house design teams who are required to use a higher level of BIM to deliver the project. In the TCE perspective, a high level of asset specificity, accompanied by a high risk of opportunistic behaviour requires more stringent administrative control and monitoring of exchange performance (Williamson, 2002). Contractual control develops and monitors rules to ensure the transaction party performs as agreed terms and conditions (Lyons and Mehta, 1997). Contractual control aligns both parties’ economic incentives to cooperate (Hennart and Zeng, 2005), and therefore, it is in the self-interest of both parties to behave in a more trustworthy fashion (Parkhe, 1998a, 1998b). Hence, we posit that:

Proposition 1: While BIM increases asset specificity, more stringent contractual control is required, which leads to higher calculative trust.

Higher asset specificity also results in higher risk management and contingency adaptability, which is a necessary element in an exchange (Williamson, 1975). In a BIM working environment that requires intensive information sharing, the communication between project team members would involve emotional expressions that influence important outcomes such as commitment to each other and to the task (Hoegl and Gemuenden, 2001). Positive emotions produced by an exchange will increase solidarity in a relationship (Lawler and Thyle, 1999). Solidarity in an inter-organizational relationship develops relational norms (Scott and Halkias, 2016). Contractual coordination and contingency adaptability that create positive information sharing in a BIM working environment enable development of relational trust. We posit that:

Proposition 2: While BIM increases asset specificity, higher contractual coordination and contingency adaptability are required thereby improving relational trust.

3.2 Environmental Uncertainty

Due to the limitation of parties to foresee every possible environmental contingency, a contract may serve as an adaptation mechanism to appropriately align the firms’ operations with the environment (Venkatraman, 1989). Contractual adaptations provide mutually agreed tolerance zones (Schepker et al., 2014) and provides guidelines for procedures for handling contingencies (Luo, 2002). For example, adaptive clauses include those prescribing procedures for handling variance and changes in the market, costs, and legislation (Mayer & Argyres, 2004), strategies for handling force majeure (Woolthuis et al., 2005), or approaches for risk allocation. The environmental uncertainty arising due to the changes in BIM may be caused by the variation works at a later stage during construction. Environmental uncertainty may arise due to translation errors or interoperability issues. Despite resulting from exogenous sources outside the scope of the project, environmental uncertainty arising from BIM can be managed. As all the necessary information is shared through a CDE, the environmental uncertainty arising from design defects and discrepancies in the design among the interdisciplinary teams can be significantly reduced through clash detection, model review in stages etc. Contractual control plays an important role in requiring contracting parties to resolve the interoperability issues at the upfront of the project, and contingency adaptability enables parties to work together and deal with the changes of BIM. Appropriate contractual control can enhance positive outcomes of calculative trust (Lumineau, 2017), whereas contingency adaptability increases flexibility and cooperativeness between the parties when handling environmental contingencies. Through flexible contractual contingency adaptability, such as assigning decision rights to a steering committee appointed by the parties to deal with the changes (Reuer and Devarakonda, 2016) arising from the changes associated with BIM, relational trust between the parties in working towards common project objectives can be developed. We posit that:

Proposition 3: Environmental uncertainty arising from BIM can be reduced through appropriate contractual control and contingency adaptability, which improve calculative and relational trust between contracting parties.

3.3 Behavioural Uncertainty

The behavioural uncertainty arising from BIM, such as potential leaking of knowledge to other parties for their own commercial use, may be protected through effective contractual control. By considering the loss/damages as a result of misbehaviour, the contractual control can increase the calculative trust of a party with regard to the other party. Working with BIM reduces the asymmetric information in construction projects, which was earlier perceived as a threat for development of opportunistic behaviours by the information holder to the other party. Such behavioural uncertainty can be minimised through intensive contractual coordination. As discussed earlier, contractual control influences calculative judgment of parties to believe in the other party, and contractual coordination enables relational trust. Hence, we posit that:

Proposition 4: Behavioural uncertainty arising from BIM can be reduced through appropriate contractual control and contractual coordination, which improve calculative trust and relational trust.

4 Conclusion and Further Research

This paper has proposed four (4) propositions that explain how asset specificity and environmental and behavioural uncertainty influence contract functions to improve...
calculative and relational trust between the project owner and EPC Contractors. The discussions showed that there is a significant influence of BIM transaction attributes on functional contracting for improving inter-organizational trust. These propositions would be empirically tested in the upcoming research work. It is important to note that the propositions made were based on the context of BIM contract provisions for the design and build contracts. They may not appropriately apply to other types of contracts, as each type of provisions may have a different influence on the strength of contract functions and trust. This paper contributes to the knowledge of trust-based functional contracting model by clarifying how transaction attributes influence the relationship between contract functions and inter-organizational trust. The propositions allow parties to use appropriate contract functions in dealing with specific transaction attributes arising from the usage of BIM. Future research can further investigate how contract functions can be used appropriately in addressing specific transaction attributes of BIM, which may impact project performance.

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CPC (2013), ‘Contract for Complex Projects’, the Chartered Institute of Building, United Kingdom.


Abstract:
The highly fragmented project nature of the construction industry, small companies and short-term thinking has made the construction industry traditionally slow in adopting new methods and technology, and the least digitalised of all the industry sectors. However, there are strong signs: Building Information Modelling, mobile and cloud computing to name a few, that digitalisation has finally reached the construction industry. Continuous change is affecting construction management processes through the changes in construction technology, manufacturing technology, technology on site, and the technology for project management and communication. Although ‘digital’, ‘digitisation’, ‘digitalisation’ and even ‘information technology’ have been clearly defined in the literature, ‘digital technology’ has been poorly defined in general and there is no agreement as to what ‘digital technologies’ means in the construction management context. In addition, there is no clear understanding about the scale and pace of the technological change. This research explores what the term ‘digital technology’ means and what it means in the construction management context, and analyses the scale and pace of the ongoing change using a literature review with longitudinal analysis. This is necessary to assist further analysis of the digital technologies themselves, but more specifically to understand the impact of the change in the construction industry.

Keywords: change, construction management, digital technology, literature review, longitudinal analysis

1 Introduction
Change is driven by global megatrends. These include rapid urbanisation, resource stress, environmental crisis, shift in global economic power, demographic and social change and accelerating technological change (CSIRO, 2016; EEA, 2015; KPMG International, 2014). These changes have impacts worldwide on nations, businesses and individuals and the change has already begun. Digitalisation as the most significant technological change (Leviakangas et al., 2011; Vass, 2015), but during the last decade there have been strong signs of DT reaching the industry. Building Information Modelling (BIM) has started a fundamental shift in the construction industry towards
digitalisation (Azhari et al., 2012; Oesterreich & Teuteberg, 2016). Next steps, already emerging, are virtual and augmented reality (VR and AR), drones, 3D printing, The Internet of Things (IoT) and wearable technologies to name a few, as well as artificial intelligence (AI) one step further (Oesterreich & Teuteberg, 2016).

This is an early stage of a larger study to understand the impact of the change on the construction industry and on the professionals in the industry. The aim of this stage of the research is to define what digital technologies mean in the context of construction management and to understand what the scale and pace of the change is. A systematic literature review was conducted for longitudinal analysis of the change, and to simultaneously define what the digital technologies mean in the construction management context. The definition of the ‘digital technology’ was supported with a traditional literature review and web search. The search criteria were set to include quality assured construction management journals between years 1982 and early 2018.

2 Research Methodology

The research question for this stage of the research was three-fold to serve the aim of the research:

1) What is the definition of ‘digital technology’? (RQ1)
2) What does ‘digital technology’ mean in the context of construction management? (RQ2)
3) What has the pace of change been in the use of digital technologies in construction management? (RQ3)

The research method chosen was a systematic literature review using longitudinal data analysis supported with an in depth traditional literature review. The underlying premise for the research method selection was that the discussion in quality assured literature reports on the latest research and development in the industry. In other words, the literature reflects what is happening with the frontline adopters of ‘digital technology’ in the industry. Following this the ‘digital technologies’ in the construction management context (RQ2) could be defined, and longitudinal analysis would serve in determining the pace of change (RQ3). Systematic literature review can be described as explicit and reproducible, quantitative, comprehensive and a structured process (Pickering & Byrn, 2014). At the beginning of this research, it was assumed that ‘digital technology’ itself could be clearly defined within the same sample for research question 1 and the question was thought to be minor, and not worthy of being a significant question. However, when searching for definitions for the DT, it became clear that the sample literature did not define ‘digital technology’ explicitly, and consequently the minor question became the major one. A wider look into academic literature including dictionaries such as Encyclopaedia Britannica and Oxford’s English Dictionary did not give an explicit definition either. In the end to find an answer to RQ1, academic literature, grey literature and various web sources, were retrieved widely considering the time limitations of this research.

The journal selection for the systematic literature review part (RQ2 and RQ3) was based on the relevance, and quality assurance and international status of the publication. Association of Researchers in Construction Management (ARCOM) journal list was used as the main selection criteria due to its focus on construction management. In addition, to address the digital technology nature of the study but still keep the focus on construction, quality assured international journals, that discuss computing in construction were added in the selection. The authors acknowledge that articles on the application of digital technologies in construction management might have been published in strictly computing specific journals instead of those focused on construction (management). However, this research specifically focused on the discussion within the construction management discipline, the computing specific journals were excluded from the sample. To ensure the quality of the journals, it required that Source Normalized Impact per Paper (SNIP) and Scopus CiteScore were minimum 0.5.

The journals included were:
- Architectural Engineering and Design management
- Automation in Construction
- Computing in Civil Engineering
- Construction Economics and Building
- Construction Engineering and Management
- Construction Innovation
- Construction Management and Economics
- Engineering, Construction and Architectural Management
- Engineering, Design and Technology
- Information Technology in Construction
- International Journal of Construction Education and Research

For the longitudinal analysis, one possible start date for the data collection search would have been the time when digitalisation started, in the 1960s’ (Hamelink, 1997). However, digitalisation did not really reach the construction industry until the 1980s’ apart from some random, isolated cases (Friedrich et al., 2011; Vass, 2015). Due to the young nature of the construction management discipline, there were no construction management specific journals at that time, regarding research and development. The first journals were established in the 1980s’. To be more specific in the sample the first were Construction Engineering and Management (established 1982) and Construction Management and Economics (established in 1983). Computing in Civil Engineering was established in 1987. Three others were established in the 1990s’: Automation in Construction (1992), Engineering, Construction and Architectural Management (1994) and Information Technology in Construction (1995). The other four chosen for the sample were established in 2000-2005. 1982 was when the first construction management specific journal, included in the sample, was established. This was set the start date for the search. To include the most current articles in the sample, the end date of the search was the date when the literature search was conducted, April 2018.

Scopus database included all the journals in the sample except the predecessor of the journal Construction Economics and Building, known as the Australasian Journal of Construction Economics and Building, volumes from years 2001-2010. These volumes were searched manually using the journal’s own website as a source. Keywords used in the database search were ‘digital’ and ‘technology’ starting with an exact phrase of ‘digital technology’ and then expanding to looser terms using Boolean operator ‘AND’ and Scopus’ proximity operators. The search was done by looking at whether the journal article titles, keywords, abstracts or subjects included the keywords.

3 Findings and Discussion

The findings of the systematic and the in depth literature reviews are discussed under the following subchapters starting from the background data regarding the sample(s) and then continuing by addressing the research questions.

3.1 Background data

The first search through the selected construction specific journals with the exact phrase ‘digital technology’ resulted in 26 articles. There were two editorials duplicating parts of the search result and one article was found to be irrelevant for the research. This resulted in 23 relevant
articles from years 2003-2018. The articles were read through in detail to find out how they defined DT.

To get a wider sample time-wise, to properly answer RQ3 about the pace of the change, Scopus’ proximity operators were used within the selected construction specific journals not just to find the term ‘digital technology’, but also the separated words. Through this search 51 relevant articles were found (including the former 23 identified).

Only six of the articles were published before 2003, so it can be argued that there wasn’t much discussion on DT in the academic literature before the 2000s.

Automation in Construction was the best source for the relevant articles, with 26 published articles using the terminology. 13 articles were found in Journal of Information Technology in Construction, 6 in Journal of Construction Engineering and Management, 3 in Construction Innovation and 2 in each, Journal of Computing in Civil Engineering and Construction Economics and Building (figure 1).

3.2 Definition of ‘digital technology’

The sample of 23 articles using the exact phrase ‘digital technology’ was looked at first for the definitions of ‘digital technology’. Most authors had disregarded defining DT, no matter how central the term was for their study. From the sample only Ibem and Laryea (2014) and Wong et al. (2018) defined DT clearly. The former built the definition of DT on the Information and Communication Technology (ICT) definition of Hamelink (1997): “Digital technologies (DTs) generally refer to information and communication technologies (ICTs) that enable the production, storage and handling of information, and facilitate different forms of communication between human beings and electronic systems and among electronic systems in digital, binary computer language.” (p. 12). The latter used a modification of a definition from Dictionary.com: “DT is considered the division of ‘scientific or engineering knowledge that deals with the establishment and application of computerised or digital devices, methods, systems etc.’; which can improve the immediacy, accuracy and flexibility of communication.” (p. 313). Regardless the completely different wording, the essence of these two definitions is somewhat similar. However, from these, two thoughts arose:

1. Is there an agreement in the academic literature, wider than just this sample, on the definition of DT?
2. Is there a difference between DT and ICT?

Looking at the Ibem and Laryea (2014) DT definition, the only difference that they made between the DT definition and the ICT definition by Hamelink (1997) is that DT uses digital, binary computer language. Already in 1997 Hamelink stated that “today the common feature of these ICT is “digitalization” (Hamelink, 1997, p. 3). Now, over 20 years later, almost all information that we use is in digital format in contrast to analog, which makes the difference between DT and ICT almost non-existent. The full Scopus database and Google Scholar were used to find a DT definition or a way to separate DT from ICT. There was not a plethora of definitions, but some were found. When it comes to separating DT and ICT from each other, Gere (2002) in the context of digital arts separated ICT as the use of computers and DT as the means by which data is captured, stored, manipulated, produced and distributed digitally. Davies and Merchant (2009), in an educational context, argued that DT entails computers, information- and communication technology (ICT) and digital media, making DT a wider concept, one that actually entails ICT. These definitions contradict with each other and also with the ones by Ibem and Laryea (2014) and Wong et al. (2018).

The reliability of dictionaries as a literature source can be argued, but when retrieved for a definition, formal dictionaries are usually a logical starting point, so they were looked as well. In resources such as Encyclopaedia Britannica (2018) or Oxford English Dictionary (2018), the term ‘digital’ and ‘technology’ are defined with multiple examples. In the Oxford English Dictionary (2018) ‘digital’ is defined as “of signals, information, or data; represented by a series of discrete values (commonly the numbers 0 and 1), typically for electronic storage or processing” and “technology” as “The product of such application: technological knowledge or know-how; a technological process, method, or technique. Also: machinery, equipment, etc., developed from the practical application of scientific and technical knowledge; an example of this.”. However, there is no specific definition for “digital technology” other than examples such as digital camera, digital media and digital data.

If we look outside the academic literature to the web, a number of definitions of DT can be found. A simple Google search “digital technology definition” brings up various online dictionary definitions. Maybe the most interesting one of these is the one from PC Magazine (n.d.) as it considers DT “a rather vague term”, “An umbrella term for computer-based products and solutions. Considering that nearly everything designed and developed these days uses computers, it is a rather vague term. Digital technology may refer to using new algorithms or applications to solve a problem even if computers were used to develop solutions in the past.”.

All in all, it seems that in the academic or non-academic literature there is no common agreement of what ‘digital technology’ is about and what the definition of it is. In some definitions DT is used as a synonym with ICT, in some ICT is a subset of DT and vice versa. Most often DT is defined through different devices, as examples of DT.

3.3 ‘Digital technologies’ in the construction management context

When it was difficult to define ‘digital technology’ as a term, maybe it is best to be viewed via various examples of ‘digital technologies (DTs)’. In this study the perspective for this was construction management.
### 3.3.1 Categorisation of the digital technologies

Categorisation assists in management of large data and therefore it was also investigated if categories already existed for DT. Ibem and Laryea identified 36 digital technologies and tools for construction procurement process in their 2014 literature survey. That article was picked up by the Scopus search as well. The categories were ‘data capturing’, ‘data processing and storage’, and ‘communication technologies and intelligent systems’. Many of the DTs identified in the report of this research can be filed under Ibem and Laryea (2014) categories as well, although some DTs belong to multiple categories, and some clearly do not belong to any. An example of the former is augmented, virtual and mixed reality. These DTs are capturing and processing information, also communicating it, but cannot necessarily be called intelligent systems. An example of the latter is digital fabrication, which is clearly a process, but is not just about ‘data processing’. Neither does it belong to the other categories. Another categorisation, somewhat similar to Ibem and Laryea (2014) comes from Hamelink (1997) for ICT in general with ‘capturing’, ‘storage’, ‘processing’, ‘communication’, ‘display’, and ‘integration and collaborative technologies’ as the categories. The same issue as the one from Ibem and Laryea (2014), where some DTs in construction management do not belong to any category and some belong to multiple categories. These categorisations need more investigation to see how the current, and possibly also future DTs in CM fit with them and maybe a new categorisation needs to be developed to accommodate them better in construction management context.

### 3.4 Pace of change

#### 3.4.1 The evolution of the term ‘digital technology’

In the figure 2 it can be seen that the term ‘digital technology’ was not found in the sample before 2003 and ‘digital technologies’ in general were rarely used in the construction context before 2005, but after 2010 its use has been relatively stable in the literature. However, Peters (2016) argued that the popularity of the word ‘digital’ is already decreasing, not because there are less DTs around us, quite the contrary; most technology is already digital and therefore there is no point anymore to add the word ‘digital’ in front.

If we use Ibem and Laryea’s (2014) definition of DT, which uses ICT and DT almost as synonyms, we can apply Froese’s (2010) three phases in the evolution of ICT to DT as well:

1. Information capturing, storage, processing and retrieval technologies, starting in 1960s’.
2. Communication systems for information and data exchange, from mid-1990s’.
3. Integration technologies that bring together data capturing, processing, storage and communication technologies, from the turn of the millennium.

#### 3.4.2 The evolution of the digital technologies

The first published article in the sample is from Paulson (1985). The article was intended to stimulate efforts to use advanced manufacturing technologies such as automation and robotics also in the construction industry. The article is over 30 years old, but so little advancement has occurred on this part of DT in construction, that the article could almost be written today. The next articles were published in 1997 by Line (1997) exploring strategy and implementation of virtual engineering teams, and by Bushby discussing a standard communication infrastructure for intelligent buildings. Both articles can be seen to be quite advanced. Visualisation started to become more important in early 2000 with Koutamanis (2000) exploring digital architectural visualisation and Dunston and Wang (2005) writing about the visualisation interface using augmented and mixed reality. Dunston and Wang (2007, 2011) were also active later in discussing augmented and mixed reality, while in the meantime digital imaging got more attention (Lee et al., 2006; Eom & Park, 2006; Styliadis, 2007; Brilakis & Sohbelman, 2008).

The term BIM was looked more in detail, as it together with virtual prototype and 3D model, found to be the most commonly discussed digital technology in the sample. It was first mentioned in 2007 by Schevers et al. (2007) along with Huang et al. (2007), who used the term virtual prototype instead. The origin of the term BIM itself was in 2002-2003, although the
object-oriented modelling approach was introduced in 1970s (Holzer, 2015), and the conceptual thinking behind it had existed even longer than that (Eastman et al., 2011).

The most recent topics (2017-2018) in the sample were Internet of Things (IoT) and smart cities, additive manufacturing and digital fabrication, but BIM was still strongly present in the discussion.

4 Conclusion and Further Research

Digital technology is changing the construction management processes, but ‘digital technology’ was poorly defined in general, and there was no agreement as to what ‘digital technologies’ means in the construction management context. In addition, there was no clear understanding about the scale and pace of the technological change. Three research questions were formulated to investigate the issues:

1) What is the definition of ‘digital technology’?
2) What does ‘digital technology’ mean in the context of construction management?
3) What has the pace of change been in the use of digital technologies in construction management?

A systematic literature review was used to answer RQ2 and RQ3 and in an depth traditional literature review including grey and web sources was used to answer RQ1.

There was no agreement within the construction management discipline or between disciplines of what the term ‘digital technology’ means. This needs further investigation. However, there is a long list of DTs used in the construction management context and the list is growing. It can be said that there has been a change, when it comes to what DTs have been discussed moving from visualisation and digital imaging to BIM, AR, VR and more recently to IoT and additive manufacturing. However, from this sample it cannot be said that the pace of change has been exponential, as one quite often hears informally.

The findings of this research assist the further analysis of the digital technologies themselves, but more specifically to understand the impact of the change in the construction industry.

The selection of the journals needs to be considered as one of the limitations of this research. The selected publications were all construction management or construction computing specific. Expanding the sample to include also purely computing specific publications or keeping the journal criteria in the Scopus search open would have resulted to a larger sample and provided more data. However, this might have resulted to a sample impossible to manage with numerous irrelevant articles. To address this limitation, the in depth (and open) literature review was completed, when the systematic literature review didn’t provide enough data to answer the RQ1. Another limitation ended being time, as the RQ1 proved to be much more difficult to answer than anticipated and it needs more investigation.

The next steps of the research are to look in more depth regarding the definition of ‘digital technology’ and to categorise the construction management specific digital technologies, starting from creation of the categories themselves.

5 References


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The content of BIM short courses in Vietnam: current approaches and recommendations

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Abstract:
In the context of spontaneous BIM education and training, there are many doubts in the Vietnamese Construction Industry about the feasibility of the Government’s Scheme to adopt BIM in building construction and facility management. Although the Ministry of Construction has issued the framework of the BIM curriculum, the reference and use in practice of this framework is still scant. This paper outlines the status of BIM training in Vietnam and identify the real needs of the trainees. On that basis, recommendations are made for the Vietnamese construction industry to dedicate appropriate human resources to implement BIM properly and efficiently.

Keywords: BIM education, BIM training, BIM short courses, educational framework, BIM human resource

1 Introduction

Many scholars affirm that human resource plays the vital role in successful BIM adoption and implementation (Tsai, Mom, & Hsieh, 2014; Won & Lee, 2010; Won, Lee, Dosiek, & Messner, 2013), especially for late adopters like Vietnam. According to Succar and Sher (2013), there are three ways to improve human resources’ capacity: higher education, on – the – job training, and professional training. Where undergraduate and postgraduate educational curriculums have no plan for developing professions related to BIM in Vietnam, it is necessary to have short-term courses with the aim of improving both quantity and quality of BIM human resources to compensate. In October 2017, The Vietnamese Ministry of Construction issued Decision No. 1056/QD–BXD announcing the pilot phase of the BIM educational framework for agencies and organizations to apply in the BIM implementation process. In Vietnam, no research has been conducted that can tell us about BIM education and training, this paper is therefore based mainly on surveys and interviews in order to fill this identified gap in knowledge. The authors analyse the status quo and industry needs, point out the training gap and give recommendations. This study attempts to provide the first perspective on this topic, suggest directions for BIM educational providers and further research.
2 Literature Review

The General Statistics Office (2018) published a press release on the socio-economic state in the first 6 months of 2018 that the construction sector maintained a decent growth rate of 7.93%, contributing 0.48 percentage point to overall growth of the national economy. The Vietnamese construction industry is expected to expand until at least 2021, due to massive investments in transport infrastructure, energy and utilities and affordable housing projects towards a better living condition for citizens. Global Construction Perspectives and Oxford Economics (2011) forecasted that the growth rate of Vietnam’s construction industry by 2020 will be similar to that of countries like China and India. According to the Government’s plan for human resources development in Vietnam (Vietnamese Government, 2011), the labour force in the construction sector nationwide will reach from 8 to 9 million people by 2020 with 65.0% trained workers. Correspondingly there will be a need of at least 0.07% (about 5,600 people) post graduates, 2.64% (about 210 thousand people) graduates. However, at present, there are only 29 universities delivering professional courses and supplying approximately 25,000 higher-education-degree holders per year in maximum for the whole construction industry (Daimam University, 2018). Whilst the cumulative number of well-educated workers from previous years is even less positive, since higher education in the AEC industry has begun to emerge recently in Vietnam. It can be clearly seen that there are discrepancies between supply and demand for postgraduates and graduates.

Early research, for example Berwald, (2008) and Denzer & Hedges, (2008) concentrated on making a shift from teaching CAD to teaching BIM in standalone courses. These were later followed by research that investigated the method and effect of incorporating BIM into college courses. Two main topics emerge in recent studies upon the BIM curriculum including: (1) examining issues concerning interdisciplinary and interoperability of collaborative BIM processes for instance (Abbas, Din, & Farooqui, 2016; Ali, Mustaffa, Keat, & Enegbuma, 2016; Hsieh, Amaranath, & Tsai, 2017; Kreuzel, Omane-Schlegel, & Hosseini, 2016; Pachpatalar, Boot, GhaffarianHoseini, & Park, 2017; Yunus, Embi, & Ali, 2017; Zhang, Schmidt, & Li, 2016), and (2) extensive research into innovative pedagogical approaches in order to carefully trade-off between advantages and disadvantages in educational outcomes of BIM courses (Adamu & Thorpe, 2016; Hernández, Fernández-Morales, & Mit, 2016; Hjelseth, 2017; Shelnour, Macdonald, McCuen, & Lee, 2017; Wu & Luo, 2016). Notwithstanding, there has been no research examining in detail the contents of BIM short/standalone courses to date.

3 Research Methodology

The authors expect to achieve the research objectives by undertaking a mixed analysis research approach as depicted in Figure 1. Initially, the current situation is analysed using online surveys. Potential BIM course attendees’ expectations are probed in terms of length, fee, instructor, topic. In parallel, data on available BIM courses delivered across Vietnam is subject to advertisement analysis. The findings are supplemented through further investigation, using interviews with the applicants for the BIM for practitioners course1. These applicants have experience in using BIM, so gathering their feedback on course content proposed by the Ministry of Construction adds value to the findings. Subsequently, the authors carry out a gap analysis to figure out how the identified industry

and academic needs might be addressed to ensure the right track for the adoption of BIM in Vietnam. As for the appropriateness of the research approach, Boynton and Greenhalgh (2004) argued that a questionnaire is suited for “a mixed methodology study” as this research is. On the other hand, interviews are especially valuable for getting the story behind a participant’s encounters (McNamara, 1999). The questioner can seek after in-depth data around the subject. Interviews may be valuable an alternative to obtaining respondents to questionnaires, e.g., to encourage explore their reactions. In addition, interviews are for the most part simpler for the respondent, particularly on the off chance that what is looked for is an assessment or viewpoint (Valenzuela & Shrivastava, 2002). More importantly, not many know about the BIM Training Framework during the pilot phase in Vietnam proposed by MOJ. The terms and definition upon BIM education, not to mention, have been a controversial cutting edge for Vietnam so far. The interviewers, therefore, had to make numerous explanations and justifications. Both questionnaire and interview were semi-structured which permits for the investigation of patterns depicting what is happening within the BIM short-term education context. At the same time, it unveils better criticism which will give understanding into clarifications for what is happening and participants’ conclusions, states of mind, sentiments and discernments.

![Figure 1. Research method of the paper](https://via.placeholder.com/150)

4 Findings and Discussion

4.1 Analysing the status quo of BIM courses

An online search enquiry was undertaken for Construction Training Courses showed the increase in attractiveness of training with BIM in Vietnam. By using the keyword “đào tạo BIM” meaning “BIM training and education”, the Google searching engine found 2,850 results in 0.40 seconds. Comparing with “đào tạo đo toàn” meaning “cost estimation training” – one of the most popular short-term courses in Vietnamese AEC industry in decades – produced 7,420 results in 0.46 seconds. This enquiry is a country-specific data because the language used for the search was Vietnamese. Table 1 shows the details of 10 random BIM-course providers whose websites contain sufficient information.

<table>
<thead>
<tr>
<th>No.</th>
<th>Titles</th>
<th>Providers</th>
<th>Location</th>
<th>Short/Long Term</th>
<th>Online (Distance learning)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Architectural designer in BIM</td>
<td>Computer Engineering Center – Ho Chi Minh University of Science and Technology</td>
<td>HO CHI MINH</td>
<td>Long-term2</td>
<td>No</td>
</tr>
</tbody>
</table>

1 The course was taking place at NUCE from 24 to 27/1/2018 delivered by domestic and foreign experts from industry and academia

2 Long-term in this paper is understood to be longer than 3 months
Half of the organizations surveyed teach BIM, of which 3 organizations specialized in teaching Revit skills, 2 organizations specialized in the teaching of setting up models to enhance the learners’ awareness of the essence of the BIM Modeller role, and the BIM Coordinator role. There is a striking point that 2 out of 10 organizations train BIM Managers – those who will manage the BIM process, policy, technology and human resources (course content shown in Table 2). It can be seen that not only do Vietnamese people train BIM modellers, but they also train BIM Managers. Because BIM in Vietnam is in the early stage of adoption, the BIM Modeller is still considered as the foundation for implementing domestic and foreign projects through the adoption of outsourcing.

Table 2. BIM Manager Training Program at RDSiC

<table>
<thead>
<tr>
<th>No.</th>
<th>Titles</th>
<th>Providers</th>
<th>Location</th>
<th>Short/Long Term</th>
<th>Online (Distance learning)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BIM Manager</td>
<td>RDSiC – NUCE</td>
<td>HaNoi</td>
<td>Short-term</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>BIM Manager</td>
<td>REDSUN</td>
<td>HO CHI MINH</td>
<td>Long-term</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>BIM Modeler</td>
<td>BIM HaNoi</td>
<td>HaNoi</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Varied BIM</td>
<td>BIM-ASM</td>
<td>HO CHI MINH</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Varied BIM</td>
<td>VnUniversity</td>
<td>HaNoi</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Revit</td>
<td>Hay Training</td>
<td>HO CHI MINH</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Revit</td>
<td>Ho c BIM</td>
<td>HO CHI MINH</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>BIM Software</td>
<td>Anabim</td>
<td>HaNoi</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>BIM Software</td>
<td>BIM Express</td>
<td>HO CHI MINH</td>
<td>Short-term</td>
<td>Yes</td>
</tr>
</tbody>
</table>

BIM courses are currently only carried out in Ho Chi Minh City and Hanoi. These are the two largest cities in Vietnam which almost all people doing BIM-related works are flocking to. Regarding course duration, 8 out of 10 courses are short-term, varying from 38 to 96 hours long per course. An article posted on The BIM Hub website in November 2016 remarked that BIM courses in Vietnam are currently delivered through short-term format at privately run training centres and internal training company departments as well as some of the universities. They are all in a hands-on style, focusing on the software tutorial rather than “a proper BIM curriculum or long-term training degree” (Pham, 2016).

Notably, BIM training service providers in Vietnam have been so far using a modern learning method – distance learning - which has a high accessibility for learners. This is also encouraging learners in proactively widening their know-how through learning from experts’ experience as well as stopping the “listening then writing” situation dominant in the past.

4.2 Reviewing requirements and expectations of learners

By referencing the contents of two BIM courses in Singapore, the authors designed a short questionnaire in Vietnamese via Google Forms. The questionnaire was circulated to Facebook groups of people who had shown their interest in BIM education and training. 111 responses were received in May 2018, of which, 102 responses were valid. Designers were the most engaged respondents with 34 valid responses (30.6%).

Figure 2 shows that the majority of respondents, i.e. 73%, want to learn BIM from both local and foreign experts. This can be viewed as a safe and reasonable choice, as learners can learn from successful practices from overseas predecessors, and to consider lessons learned from domestic experience.
The results shown in Figure 4 show that the demand for BIM training amongst those sampled in Vietnam is currently somewhat concentrated in the implementation segment. This is justified when BIM is just seen as a stepping stone in Vietnam. However, there are a few organisations that have been around and using BIM for quite some time, so the view that BIM is in the initial stage of implementation is not consistent across the whole industry. However, Vietnam is not without urgent need for BIM training for managerial levels. Middle managers and senior managers in construction firms are gradually realizing the importance of BIM and this may be the key success factor for the BIM roadmap in Vietnam, similar to other preceding countries (Ding, Zuo, Wu, & Wang, 2015; Eadie, Browne, Odeyinka, McKeown, & McNiff, 2013; Won & Lee, 2010).

As reflected in Figure 5, with the exception of the four 'other' responses made in the open response text box, the respondents paid almost the same attention to all items raised in the course of BIM Implementation as follows:

- BIM fundamentals
- BIM design process
- Design coordination and documentation
- Design analysis
- Construction planning and coordination

This result shows that the respondents wish to learn a broad range of topics from the course, not a single or specific in depth. This approach is relatively suitable for a short-term course but requires more effort from the trainees to grasp the range of topics covered.

Otherwise, the course will not make an impact on the attendee and the time will be wasted—described in the Vietnamese proverb as ‘riding a horse to view flowers’.

Similar to the BIM implementation course, there is no sharp difference among topics. Looking at the details as displayed in Figure 6, the respondents indicated that the “Introduction to BIM Implementation” was the most necessary element, followed by the “BIM Step-by-Step Plan for Enterprises” and “BIM project execution plan”. It is easy to understand that BIM implementation is the sound foundation for BIM management. Following this, respondents want to get “quick wins,” or “instant noodles” through pilot projects. This approach promises to bring results soon, and the result is quick to see. Still, high-level and longer-term strategies are needed, as stated in the following quote from the BIM literature:

“When it comes to BIM, many think of an advanced software system. However, the transformation into BIM is more than a technological transition, it’s a cultural change, a revolution in thinking. Therefore, the adoption of BIM requires a careful planning, selecting the right tools, training the entire system from top management downwards. The BIM strategy should equip the company with a thorough preparation from knowledge, skills and spirit to successfully adopt BIM” (Anabim Education, 2017).

Regarding course fees, the largest proportion of respondents, i.e. 37%, agreed with the range from $100 to $150 for a 2-3-day course (see Figure 7). In addition to remarks that fees do not matter and/or depend on the magnitude of knowledge, some respondents said that there should be incentives as well as calls for funding from enterprises and NGOs.
These remarks are noteworthy for those who intend to hold a BIM course, as fees are a big issue to consider for attendees. Learners will consider carefully whether or not they are involved, because tuition costs are relatively high, typically accounting for roughly 20-30% of their monthly salary (see Figure 8).

Figure 8. Monthly salary of construction engineer in Vietnam
Source: Career Builder (2018)

Figure 9 illustrates the prospects for BIM courses in the format of on-the-job training. Although only about 40% of respondents claimed there is a need, nearly 47% responded "Not sure." This signal is relatively good news for training providers, though they will need to try to persuade those people who are hesitating. Concurrently, it is necessary to keep informed the group in need, as well as find ways to approach people who are saying 'No' to on the job BIM courses.

4.3 Assessment of BIM practitioners

On occasion of application for the course of BIM for Practitioners, the author interviewed 30 applicants in two formats - face to face interview and interview by phone - on the period from 2nd to 7th of January 2018. The content of the interview is examining feedback on the necessity of contents incorporated into the government BIM Training Framework during the pilot phase (Ministry of Construction, 2017). Contents proposed by the Ministry of Construction are shown in Table 3.

The evaluation scale is to set a Likert score of 1-5 so that the respondent evaluates the necessity of each content, with 1 being Very Unnecessary, 5 being Very Important. The results are presented in Table 4.

Table 4. Feedbacks on the necessity of contents incorporated into the BIM Training Framework during the pilot phase in Vietnam proposed by MOC

<table>
<thead>
<tr>
<th>No.</th>
<th>Contents</th>
<th>Mean</th>
<th>Mode</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Overview of BIM</td>
<td>4.9667</td>
<td>5</td>
<td>0.3399</td>
</tr>
<tr>
<td>2</td>
<td>BIM environment, platforms and tools</td>
<td>4.6667</td>
<td>5</td>
<td>0.3727</td>
</tr>
<tr>
<td>3</td>
<td>Standards, guidance on BIM and BIM implementation at the project level</td>
<td>4.3333</td>
<td>5</td>
<td>0.5755</td>
</tr>
<tr>
<td>4</td>
<td>Developing BIM execution plan for organisations</td>
<td>4.7000</td>
<td>5</td>
<td>0.3399</td>
</tr>
<tr>
<td>5</td>
<td>BIM for consultants and contractors</td>
<td>4.7000</td>
<td>5</td>
<td>0.3977</td>
</tr>
<tr>
<td>6</td>
<td>BIM and design analysis</td>
<td>4.9000</td>
<td>5</td>
<td>0.3859</td>
</tr>
<tr>
<td>7</td>
<td>Linked model and collaboration on the BIM platforms</td>
<td>4.4667</td>
<td>5</td>
<td>0.3999</td>
</tr>
<tr>
<td>8</td>
<td>Simulation of schedule on BIM platforms</td>
<td>4.2667</td>
<td>5</td>
<td>0.3055</td>
</tr>
<tr>
<td>9</td>
<td>Estimation on BIM platforms</td>
<td>4.4667</td>
<td>5</td>
<td>0.3859</td>
</tr>
<tr>
<td>10</td>
<td>Case studies</td>
<td>4.4667</td>
<td>5</td>
<td>0.3977</td>
</tr>
<tr>
<td>11</td>
<td>Q&amp;A and test</td>
<td>4.3333</td>
<td>5</td>
<td>0.3977</td>
</tr>
</tbody>
</table>

In general, the respondents were very enthusiastic about all the content proposed by the Ministry of Construction (the Modes all score 5 meaning very important). The “Linked model and collaboration on the BIM platforms” is considered to be the most necessary, with a very high average rating of 4.900 and the lowest standard deviation of only 0.3
indicating uniformity across respondents. In addition to the content "Q&As and test", although still reaching 4,400, the need for content on "Estimation on BIM platforms" received the lowest rating among 10 contents. This is understandable because the respondents' job roles are varied, not limited to QS or estimators, so their attention is beyond technical issues. What is more, there are two noteworthy items - those are "Simulation of schedule on BIM platforms" and "Q&As and test" having the highest standard deviation, respectively 0.8055 and 0.7888, shows a relatively large gap in the assessments of the importance of these two items among the respondents. Of course, there is a need for a broader survey to verify this framework, but the results of the interviews show a positive signal. To a certain extent, it can be said that the Ministry of Construction has proposed training subjects that closely follow the needs and requirements of professionals.

5 Conclusion and Further Research

This study used broadly quantitative data collection and analysis methods. A follow-up study using mixed methods analysis, or purely qualitative methods would help to add the richness and depth of information which has been gathered here. Although the survey and interview were carried out at a different time, they both give similar results. Subjects and contents are generally clear and relatively equal in terms of the need for short-term training courses, however, they need to co-ordinate contents are generally clear and relatively equal in terms of the need for short-term training courses, however, they need to co-ordinate.

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7 References


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Design Economics Through Use of BIM as a Decision Support System

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Abstract
Within the field of architecture, engineering and construction, Building Information Modelling (BIM) has attracted vast interest from both academics and practitioners. This is mainly attributed to the significant time and cost savings that the technology offers when implemented on construction projects. A relevant application of BIM is also in its use for decision making, particularly when it comes to contrasting choices of shape design and morphology to adopt for a specific project. To address the lack of appropriate assessment approaches that capture the differences between proposed designs in BIM, a framework is proposed in this work to aid decision makers in choosing between alternative designs for construction projects. This is achieved through the integration of BIM with material libraries, project schedules and machinery inventory. A set of design parameters are established, with emphasis on morphology and shape design, to allow for a reasonable comparison across proposed project designs. The framework is implemented on a realistic case example, highlighting its applicability as a decision-support tool for construction project design assessment and selection.

Keywords:
Design economics, Building morphology, BIM, Decision-support system

1 Introduction
Traditionally, when it comes to construction projects, the emphasis has been on accounting for the size of the project and the quality and quantity of materials adopted on the project, as major influencing factors for determining associated costs. Little emphasis is placed on the use of the building morphology and its design economics, as the basis for making decisions related to project and building management. The morphology of a building has been shown to have a significant impact on the associated construction and operation costs (Xu et al., 2017; Zeiler, 2017), yet there is still insufficient research that supports linking the morphology of buildings with its performance and cost (Ashworth and Perera, 2015).

The construction industry has recently witnessed a paramount shift in the way that projects are managed, through the introduction of building information modelling (BIM). Adoption of BIM on construction projects allows for the modelling and gathering of useful information that guide the progress of work throughout all phases of a project (Hammad et al., 2017). Its possible areas of application in the construction sector, including design (Chi et al., 2015), cost management (Smith, 2016), coordination (Bryde et al., 2013), schedule management (Li et al., 2017), risk management (Zou et al., 2017),

272.
and building management (Pishdad-Bozorgi Pardis, 2017), has attracted vast attention from practitioners in construction.

Yet the importance of design morphology and its impact on the construction project during and after its construction, is still not explored. As a result, a framework that utilises the powerful capabilities of BIM for use in design economics, is still lacking. This study presents a decision-support system that is based on linking BIM and the various factors of design economics; the integrated design factors are used to conduct a life cycle costing analysis (LCC), which is a tool for determining the most cost-effective design throughout the life cycle of a project (Cabeza et al., 2014). The overall result is a system that can address issues impacted by building shape design and morphology throughout the life cycle of the project, leading to efficient and effective project design, cost and operation.

This paper is organised as follows. The next section presents the design morphology BIM framework. A discussion of the main design economics factors that are integrated into the proposed framework then ensues. A case study is presented to demonstrate the applicability of the framework.

2 Framework

The framework proposed in this paper is displayed in Figure 1. Three main sections of the framework are highlighted, namely the input design, the databases which is formed from lists of materials and resources required for the project, and finally the algorithm developed which integrates design economy factors with LCC. The input designs comprise the architecture and engineering drawings that produce the building design, in compliance with the requirements of the client, in addition to the site layout that exists before the construction of the project. These drawings will need to be converted into an applicable BIM file, if produced in a 2-dimensional format. The software of choice for BIM utilised in this research is Revit (“Autodesk Inc.,” 2018).

The second part of the framework is the database consisting of the limited resources available to the project; this includes the materials that will be utilised and the construction equipment required during the different phases of the project. Such information is used to determine the initial cost associated with the design proposed by the architects/engineers and which will need to be improved via the framework.

The third component is the algorithm which has been developed in Dynamo (“Dynamo BIM,” 2017) in order to integrate it with BIM files. Dynamo is visual programming tool that provides access to the Application Programming Interface of Revit. Visual coding is then used in order to combine the 8 elements of design economics identified, including Site considerations, Building size, Sustainable design, Shape efficiency, Grouping, Buildability, Structural morphology and Standardisation. The algorithm analyses the various design economics factors, via an LCC approach, in order to account for the full life cycle of the project, and hence produce an alternative design that minimise the life cycle cost of the project. Combining the building designs with the database modules, consisting of materials and resources available on the project, ensures that the end design is one that is in line with the limited number of resources assigned to a project.

When calculating the LCC for the designs proposed, the algorithm developed accounts for the initial costs associated with the building design (as determined by the materials and resource requirements), the installation costs associated with activities required for producing the design, the energy cost associated with construction and operation phases of the building, any maintenance costs, and end of life costs associated with demolishing/deconstructing/recycle the building. A deterministic approach is utilised in the LCC, with the required input computed based on historical data obtained from the organisation for which this framework is implemented.

The developed algorithm accounts for a number of significant factors that impact the design economics of a building. As a result, the main focus of the algorithm is on varying the morphology factors listed and accommodating the changes in a BIM file in order to end up with an optimised design that minimise LCC. The next subsections explain each of these factors.

2.1 Site consideration

Given that each construction site has its own unique characteristics, the framework, through the developed algorithm, considers site-related features by altering the design of the building to suit the site characteristics. This includes the size of the site, the location of the site and the availability of main services that connect the site to electricity and water. The semantic information linked into the BIM file enables the extraction of information regarding the cost of construction in accordance with the location of the site. It is thus essential that the algorithm initially acquires information about the site location in order to determine the most suitable construction method to adopt for the input design. Ground factors of the site are also accounted for, in order to ensure that the foundation system chosen by the engineer is the most suitable one.

2.2 Building size

The building size needs to be determined based on the requirements of the client. This is one of the most integral factors of a project, since the size of the project will directly influence the construction costs associated. Based on information derived from the
database modules, the algorithm is capable of making recommendations regarding the size of the building in order to meet the requirements of clients while at the same time ensuring that resources and material are sufficient to cover the needs of construction. This is achieved by a parametric modification of the elements forming the building structure, until the costs associated are lowered. Economies of scale are also accounted for where the unit cost of buildings decreases with increasing size. An important measure that the algorithm relies on when computing unit cost is the wall-to-floor ratio: a larger internal plan will typically lead to a lower ratio.

2.3 Sustainability measure
To ensure a sustainable project design, the proposed algorithm implements the concept of LCC through environmental consideration. LCC accounts for all costs associated with the stages of a project’s life, starting with raw material extraction, through material processing, manufacturing, construction, maintenance and end of life disposal. In addition to the environmental consideration, social and economic costs are also taken into account. Overall the following is assessed via the algorithm when proposing an alternative design:

i) the quality and durability of materials. The better the durability of the materials used, the less frequent they need to be replaced

ii) designing the project to align with the surrounding environment, through integration of existing natural terrain of the ground with the proposed building design

iii) ensuring that noise pollution during construction remains minimal, via selection of appropriate resources that are associated with low noise-emitting activities.

iv) ensuring that measures such as sunlight, passive ventilation and privacy of the building is accommodated for via window locations on the building design.

v) when selecting materials to adopt in the building design, preference is given to material that are locally sourced. In addition, low toxic materials would always be preferred (i.e. ones with low environmental impact)

vi) ensuring that operational energy remains low through the utilisation of active and passive sustainable design measures such as ventilation, solar power, thermal massing and optimum U-value selection for the building envelop.

At the same time, green building standards can also be integrated with the proposed framework in order to enable the design of a project that complies with the requirements set in these standards.

2.4 Planning Efficiency
The algorithm within the proposed framework has the capacity to alter existing designs in order to ensure that space is efficiently utilised. A huge emphasis is placed on reducing the circulation space. Depending on the type of building, different ratios of usable to non-usable space are defined. Building regulations are still enforced to ensure that the resulting design complies with standards.

Part of the planning efficiency is to also establish the optimum plan shape, through utilising measures such as the wall-to-floor ratios, floor space index and open space ratios. This is necessary to ensure the overall costs of the project are kept at a minimum, while ensuring that a design is produced that complies with built density requirements specified by regulating bodies (i.e. councils etc.). Complex shapes are often associated with more corners and hence a higher ratio of walls to floors. This impacts the productivity of workers. The algorithm tries to achieve a balance between the requirements set out by the client and the measures that produce the most effective plan shape. Additionally, the site shape needs to be considered when proposing an appropriate building shape.

Another measure that the proposed algorithm accounts for is the height of the building. It is well known that construction costs associated with tall buildings are generally higher than those associated with low rise buildings. Vertical transportation of materials during construction are considered along with the additional engineering services required with increasing building height. The height of the building will also influence the choice of the foundation system and structural frame to be adopted for the building. High-rise buildings can also lead to a less efficient plan, with more area allocated as circulation space for staircases and lift shafts. The algorithm will propose appropriate storey heights depending on the use of the building and the provision for ducting services and pipes necessary to install in the ceilings of the building.

2.5 Grouping
When more than one building is involved, the proposed algorithm will attempt to find an optimum grouping arrangement of buildings, either via a horizontal or vertical stacking. This can be achieved by interlinking services and structures of the buildings together in order to save on construction and operation costs.

2.6 Ease of construction
The algorithm will attempt to identify complex construction procedures that will likely slow the progress of construction works. Alternatives are provided to accommodate for such processes. A link between construction methods adopted in the region and the efficiency levels expected is input to enable the user to conduct an encompassing analysis. In addition, the choice of cladding systems that ease the process of construction is programmed based in the structure and shape of the building.

2.7 Structural morphology
One of the most important considerations that the framework accounts for is the nature of the structure of the frame adopted for the project being analysed. The choice between plausible structure types is made based on the cost of construction, speed of construction, environmental consideration and operational energy. The climate of the region in which the project is constructed also plays a huge role in the selection of an appropriate structural system.

Based on building cost and whole life cycle cost, the geometrical form and shape of the structure of the building can be selected. This includes the arrangement of columns within the building, the size of the structural elements used, the layout of rooms and space inside the building and the architectural appearance specified by the client.

2.8 Standardisation
Standardised designs are known to be associated with faster construction schedules. The algorithm will analyse the input design and make suggestions on the use of prefabrication/modularisation in the project. This is based on the degree of the standardisation that can be achieved in the existing project.
3. Case Study

In order to demonstrate the applicability of the proposed framework, it is implemented on the design of a residential complex in the south-east of Sydney, Australia. The client requires the construction of four similar residential buildings, with each building containing 6 units. The initial designs specified by the architects were modelled in Autodesk Revit (“Autodesk Inc.,” 2018), as shown in Figure 2A. The algorithm was developed through visual programming in Revit using Dynamo. The user is required to input the database of resources and materials. An alternative design was then proposed depending on the design economic factors included. The objective was to reduce cost, reduce environmental impact and reduce the time of construction. The result of the alternative design is displayed in Figure 2B.

Figure 2 A). Original design suggested by architect B). Alternative design proposed by framework

The alternative design suggests a steel frame with modular units constructed off-site instead of the original concrete structure. This resulted in a reduction of the work schedule by 15% as shown in Figure 3. Environmental cost was also reduced on average by 17.5% due to a 16% reduction in embodied energy and a 19% reduction in operational energy as shown in Figure 3. Even though the cost of the structure now increases by 24%, the overall construction cost of the building decreases by 22% given the more efficient space use and integration of services and structure suggested by the developed framework. The resultant design satisfies both resource and budget limits imposed by the client.

4. Conclusion

This paper presented a design economic BIM-integrated framework that utilises parameters based on the building morphology and design economics to improve on the economic aspect of building construction and operation. An LCC approach was utilised in the cost computation. Additionally, other sustainability dimensions, such as social and environmental considerations, were also incorporated into the framework. The framework is designed using the visual programming capability provided by Dynamo. Factors incorporated into the algorithm of the framework include the size and layout efficiency of the project, the buildability, the structural morphology, building size and site considerations. To demonstrate the applicability of the proposed framework, it was examined on a realistic project in Sydney, Australia, to improve its life cycle design economic aspect. The alternative design suggested by the framework resulted in a 22% saving in cost, 15% saving in time and a 21% improvement in design shape efficiency. Future studies will focus on testing the developed framework on various buildings uses and integrating it with an optimisation tool to further improve the designs.

5. References

This study investigates how the need to amend construction contracts to suit individual project specific needs is creating a climate in which disputes are increasing. According to the short and long range cycle. The Intelligent Contract is the logical next step towards this goal to fill the gap; however, the relevant literature is scarce and there is lack of in-depth investigation to identify drivers and barriers of using this technology. This study investigates how Intelligent Contracts could be best implemented within the construction industry and how the current information modeling systems could offer the initial catalyst for their adoption. The paper aims to identify whether BIM offers a definitive platform for the implementation of Intelligent Contracts in the Construction Industry. The benefits of this new approach is greater administrative efficiency with reduced costs and less disputes. Surety of payment would lead to additional small companies being able to operate with confidence in the sector. Creating an environment where the sophistication of data exists from all stakeholders, that will be the fuel for a central Intelligent Contract system, will require a huge step towards the digitisation of the industry. It is predicted that increasing levels of digitisation occurring in pockets around the Construction Industry will eventually lead to the Internet of Contracts.

Abstract:

The new wave of multi-party, alliancing and collaborative tools contracts have paved the way for the disruptive change required to finally force collaboration into the construction industry. It is widely believed that a pre-requisite is the incorporation of Building Information Modelling in order to bridge the gap between the phases of the development cycle. The Intelligent Contract is the logical next step towards this goal to fill the gap; however, the relevant literature is scarce and there is lack of in-depth investigation to identify drivers and barriers of using this technology. This study investigates how Intelligent Contracts could be best implemented within the construction industry and how the current information modeling systems could offer the initial catalyst for their adoption. The paper aims to identify whether BIM offers a definitive platform for the implementation of Intelligent Contracts in the Construction Industry. The benefits of this new approach is greater administrative efficiency with reduced costs and less disputes. Surety of payment would lead to additional small companies being able to operate with confidence in the sector. Creating an environment where the sophistication of data exists from all stakeholders, that will be the fuel for a central Intelligent Contract system, will require a huge step towards the digitisation of the industry. It is predicted that increasing levels of digitisation occurring in pockets around the Construction Industry will eventually lead to the Internet of Contracts.

Keywords: BIM, Collaboration, Construction, Intelligent Contract.

1 Introduction

At the centre of all construction projects is the contract between the client and contractor and, as any construction project is a relatively complex process, the industry has demanded contracts of greater sophistication as the sector has evolved. The recommended use of one single standard form of contract for the construction sector has existed since the 1960’s (Banwell, 1964). Organisations compete to promote their own suite of contracts but the perceived need to amend construction contracts to suit individual construction projects still exists as does the careful consideration of project specific parameters to be inserted in order to achieve a successfully executed contract (Foreward, 2002).

The construction industry has a reputation for being adversarial and motivating dispute. In Australia, there is evidence to suggest that 50% of all legal costs associated with construction projects are a direct result of dispute (Chern, 2010). According to the ARCADIS Global Construction Disputes Report 2016, the global dispute value is down from US$51 MILLION in 2014 to US$46 MILLION in 2015 but the average length of these disputes has increased from 13.2 months to 15.5 months in the same period. The continuing trend observed over the past 6 years is that disputes are increasing in both value and in the length of time taken to resolve them ( Arcadis, 2016).
The deep-rooted cultural aversion to the trusting approach has seen partnering and framework agreements falter within the industry (J Mason, 2017). The problem of gaining trust has baffled social science since the day of Thomas Hobbes (Ceric, 2015). In the United Kingdom, standard form contract providers stand at a crossroads on whether multi-party contracts, encouraged by the partnering ethos, is the way forward (Saxon, 2016). It is postulated that the solution to the trust issue is to make contracts "trust-less." Truly autonomous, intelligent contract minimise the need for conventional human management. Furthermore, using blockchain-type technology, trust can be built into the model through immutable records in a distributed ledger. The full or semi-automation of contract administration alone which could be achieved through implementing Intelligent Contracts would stand to save the industry an attractive percentage of any projects costs (Cardeira, 2015). The fanfare of BIM technology brought with it all the pomp and promise of a technology saviour that would transform the industry. The level of BIM usage and the capabilities of the major platforms are not at a stage yet where the platform could be harnessed to facilitate the implementation of Intelligent Contracts. Potential user numbers would not be viable and technology capabilities are not sophisticated enough.

Put simply, intelligent (or "smart") contracts are computer protocols that facilitate, verify, or enforce the negotiation or performance of a contract, or that obviate the need for a contractual clause (Szabo, 1994). The proposal of embedding the terms and conditions of an agreement into a physical item contrasts immensely from a traditional paper contract which, upon being agreed, is used only when the parties are in dispute.

Intelligent Contract is the term used when a contracts purports to manage itself (J Mason, 2017). The Intelligent Contract will set out the requirements and decision inputs (hold points) that will start a series of if / then's that will execute the terms of the contract between client and different members of the project team, main contractor, sub-contractor to design, monitor, approve, tender, install, certify and take handover of the built asset (Hughes, 2017). The ‘black and white’ or ‘1 or 0’ execution of an Intelligent Contract is a huge obstacle to overcome in adopting the potential technology in the construction industry. This is due to the complexities of the construction process requiring judgement and discretion which would normally be handled through sublety and refinement in the language of traditional contracts (J Mason, 2017). The language of code does not allow for grey areas, but could this be the catalyst for changing the combative attitude of the industry by forcing parties to agree most, if not all, terms prior to engagement?

By creating an all-encompassing contract process - that: ensures all parties adhere to the terms agreed; offers protection of payment, insurance and data; as well as the potential to increase efficiency and reduce risk - it should make the successful implementation of Intelligent Contracts the top priority for the Construction Industry. The first step to making this possible could be to build on the momentum that the BIM agenda has created and to complement the BIM platform before evolving into further technologies. By replacing the ‘hammer’ that is the current construction contract with a more streamlined, efficient and collaborative tool that Intelligent Contracts could be, perhaps the industry will stop treating each other as nails.

The aim of this paper is to show how Intelligent Contracts could be best implemented within the construction industry and how BIM could offer the initial catalyst for their adoption. The industry’s adversarial history has led to a point where a truly innovative and disruptive change is required at the very heart of the binding contract in order to advance the sector into the digital age. Is the need to force parties to trust, rather than appeal to them to do so, required after the slow acceptance of the collaborative culture championed in the previous decades?

2 Literature Review
Seeking to address the issues raised in the numerous reports on construction sector practices, the industry has responded with many tools and process that have provided guidance on the best practice of implementing collaboration. However, the successful implementation of collaborative technologies is reliant on the environment being collaborative. This has at times created a ‘cart before the horse’ scenario as many of these technologies have been produced in order to create such an environment (Briggs, 2006). Kvan (2000) claims collaborative environments cannot be created using software tools and that collaborative technologies are more successful when collaborative working environment already exists prior to implementation.

2.1 BIM and collaboration – an evaluation on the current status and future

The United Kingdom Government Construction Strategy (GCS) 2011-15 mandated the UK industry to use BIM level 2 on Government projects and must demonstrate collaborative practices in order to win Government contracts as BIM is a tool that encourages open, collaborative working (HMG, 2015). BIM increases the scope and speed of data exchange which highlights the input required, the timing of the input and the reliance of the data from any member of a project team. The proposition is that this process enables and depends upon increasing collaboration as a means for success (Mosey, Howard, & Bahram, 2016). For BIM to be truly used to its full potential, a collaborative environment must be present to offer ‘real-time’ collaboration. The 2015 NBS National Survey noted that 57% of those surveyed agreed with this and most described their contract form as collaborative, especially users of the NEC3 or PPC2000 form of contract (Mosey et al., 2016). Some standard form contracts have adopted a light touch in relation to the inclusion of BIM provisions with many using clauses that simply refer to the Construction Industry Council (CIC) BIM Protocol. The CIC Protocol is designed to encourage BIM adoption through a series of supplemental contract documents which are signed by the client and then bi-laterally with the main contractor, subcontractors and consultant that make up the project team. This network of bi-lateral contracts is the alternative to a multi-party contract and serves the purpose of creating the necessary ‘consensus ad idem’ well in its absence (J Mason, 2017).

The flawed nature of the industry’s attitude is evident in the CIC Protocol (Jim Mason, 2016). The lack of warranty in relation to the integrity of electronic data transfer, before and after transmission, and the lack of liability for the modification, amendment, transmission, copying or use of BIM models other than for the agreed purpose. The most obvious limitation of the CIC Protocol however is in clause 4.1.2 where the production of models in accordance with the Agreed Levels of Detail specified in the Model Production and Delivery Table to ‘reasonable endeavours’. As (Mosey et al., 2016) states, “this is a lower, less clear duty of care than the widely accepted standard of reasonable skill and care.” This is of course unclear and has been interpreted by the courts in many ways according to the context in which it is used.

A growing interest in the role that multi-party contracts play in successfully supporting BIM enabled projects has been evident in the use of PPC2000 and other comparable multi-party contracts that have been developed in Australia and the USA (Mosey et al., 2016). The cooperative nature of these contracts creates the necessary environment for BIM to be optimised. When we contemplate the implementation of BIM level 3 the level of collaboration is starting to rely more on stigmergic collaboration where each piece of work is indistinguishable from the next and the author is not notified of any changes to their contribution by other project members (Elliott, 2006). Collaboration at this level is most certainly reliant on a multi-party contract, if only to deal with the liability of the project insurance (Jim Mason, 2016).

2.2 Barriers of utilisation of information modelling and intelligent systems

Technology adoption refers to steps taken through which a decision maker passes to evaluate a new technology and make a decision to accept or reject it. In the next step, the decision maker organisation enters into a new process of using the technology which is called implementation (Sepasgozar, Davis, Li, & Luo, 2018). This suggests that utilised technology could add value to the organisation, and if this process of utilising the intelligent contract is successful, it will be a source of competitive advantage and is critical for the organisation to collaborate effectively with the stakeholders. The success of implementing any new technology depends on many factors. For example, personnel’s attitudes toward new technologies are shaped by the risks involved in using unknown means and methods, the difficulty of implementation, financial risks, and the perception of other workers’ attitudes toward new technologies (Tatum, 1989). While BIM is expected to deliver many benefits to the industry, a range of barriers have hampered its widespread implementation. (Liu, Xie, Tivendale, & Liu, 2015) categorised these into five major groups: lack of a national standard; the high cost of application; the lack of skilled personnel; organisational issues; and legal issues. Standards are common throughout the every facet of the AEC industry but successful BIM implementation requires the development of new standards pertinent to the technology (Liu et al., 2015). The lack of appropriate governing standards for sharing data between all stakeholders in the development process is seen as a barrier to the technology being accepted. In the 2014 Pinsent-Mason Survey it stated, “The overriding message…points to clear collaboration if BIM is to be a success.” However, they provide evidence showing that collaboration is not a new objective or concept for the construction industry, and policy makers and industry stakeholders have strived to create a more collaborative environment, albeit limited success (Roberts, 2014).

Data inconsistency is the most prominent data-related barrier as well as data compatibility between stakeholders. Willingness to share information among project stakeholders is critical to BIM, therefore any issue with transmitting and reusing the BIM data constitutes a very real barrier to BIM implementation (Ahinna & Venkatesh, 2014). A survey taken by the National Building Specification (NBS) organisation showed that a single BIM data platform is yet to be established and 26% of BIM users relied on multiple pieces of software (J Mason, 2017). The interoperability of BIM software is seen as a key issue, but it is one that is being addressed, by new tech company flux.io, in the next wave of AEC technology. Flux.io are investigated further in this paper regarding their solution for this issue.

Addressing the legal aspects of BIM development is also necessary and intellectual property rights is a topic that has caused some nervousness around BIM (Jim Mason, 2016). If owners pay for the architectural design of construction projects, they may claim ownership of the design documentation but licensing problems may arise when other stakeholders contribute data that is integrated into BIM (Azhari, 2011). Determining who controls access to the BIM data and is thus responsible for inaccuracies is an aspect that could bring about a great deal of risk (Liu et al., 2015). Stakeholders require security of confidential data in the BIM model, but a range of legal and security issues have been identified in connection with the administration of construction projects within an electronic environment (Chynoweth, Christensen, McNamara, & O’Shea, 2007). New legal solutions will be required in order for BIM to be the vehicle by which project delivery is achieved (Jim Mason, 2016).
3 Research Methodology

The research focuses on the qualitative data to understand people’s perceptions of the existing contract and BIM environment in the industry in order to discuss the possibility for Intelligent Contract implementation. The views and perceptions of interviewees form the backbone of this study. Empirical research has been collected to support the findings in the Literature Review and develop a practical understanding of the technologies. Due to the embryonic nature of the subject, case studies were not found to exist. Primary research will be collected through selected interviews from a cross section of the construction industry. The decision to focus the data collection on a chosen selection of sources is due to the incipient nature of the subject. The alternative strategy of collecting data from a larger uncontrolled group would have resulted in more generalised and unreliable response due to the limited knowledge of the subject matter that currently exists. A base questionnaire was developed in order to provide consistencies with the interviews, but this acted as a guide as each subject offered specific focus for discussion due to the differing backgrounds of the chosen subjects. The research is limited due to the cutting edge nature of the subject and lack of real world application of the Intelligent Contract technology in construction. This paper investigated theoretical and conjectural literature based on progressive ideologies and commented on the possible applications within construction. As the subject of the interviews were extremely theoretical, the most effective responses were from a senior management level, who can be more difficult to access. A selected number of 5 interviewees were chosen from the respected fields of project management (with BIM expertise), legal, facilities management, construction dispute and construction technology software. Due to the extended nature of the interview process with each subject, the limitation of the focused nature of the data collection does bring a limitation to the research. For this reason, each subject was chosen carefully from their respected fields in order to give a more rounded viewpoint from the cross-section of professions chosen. The selected professional fields offer the complete cross section of expertise for this subject across the construction industry required to give a well-rounded commentary on the Intelligent Contract concept. Access to a large network in a range of professions across the Sydney construction industry, along with the willingness of interviewees from further afield has been largely accommodated from my work as a client-based Project Director.

4 Findings and Discussion

The construction industry is a very fragmented sector with poor efficiency across all aspects of the development cycle. While production rates have remained the same wages and resources have increased (McNamara, 2002). Unless we embrace new technologies to increase productivity the industry will struggle. By embracing new technologies greater value can be harnessed through the procurement process by opening up a global supply chain network.

“If we don’t improve efficiency and productivity, Streamline global supply chain and embrace technology we will continue to fail. I’m waiting for the tech sector, someone like Google or an Elon Musk to come in and take over.” CC

The perceived lack of collaboration and penchant for litigation was also exhibited by the following responses.

“The industry by nature has to collaborate, which doesn’t necessarily happen.” HC

The general consensus between all interviewees was that current construction contracts are merely used as a weapon which predominantly favoured the bigger player in any given dispute. Contracts are seen as a reactive tool to be used when situations demanded.

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"The only time a contract comes out is if the relationship has broken down and you have to refer to the 'rulebook'." CC

Table 1 shows a list of factors relevant to the Intelligent Contract implementation and barriers in the construction industry. Inconsistency and ambiguity of construction contracts was also identified as a major factor for the adversarial environment within the sector. This is seen as a major flaw in the drafting of contracts in not only the primary contract but subsequent sub-contracts. Clarity of terms and a less legalese approach to drafting would mitigate this factor, but the human element involved in administrating the contract would still offer exposure to mis-interpretation.

Table 1. Selected factors and quotations.

<table>
<thead>
<tr>
<th>Factor ID</th>
<th>Factor</th>
<th>Participating ID</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Construction Contracts</td>
<td>CC</td>
<td>Commercial Director and former Head of BIM Development for a global property organisation</td>
</tr>
<tr>
<td>2</td>
<td>Risk</td>
<td>AA</td>
<td>The MD of a construction dispute resolution firm</td>
</tr>
<tr>
<td>3</td>
<td>Dispute Management</td>
<td>JL</td>
<td>Project Director - published papers on smart contracts in construction</td>
</tr>
<tr>
<td>4</td>
<td>Requirements for Intelligent Contract</td>
<td>CC</td>
<td>The Intelligent Contract concept will definitely create more 'up front' work for the legal profession</td>
</tr>
<tr>
<td>5</td>
<td>Payment Management</td>
<td>CC</td>
<td>Project Director - published papers on smart contracts in construction</td>
</tr>
<tr>
<td>6</td>
<td>Data Analysis</td>
<td>CC</td>
<td>The finance side of projects may one of the main drivers for Intelligent Contracts</td>
</tr>
<tr>
<td>7</td>
<td>BIM Integration success</td>
<td>CC</td>
<td>The finance side of projects may one of the main drivers for Intelligent Contracts</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

286.

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The onerous nature of administering contract in current practice was also a shared opinion. For instance, in a dispute situation where there has been a delay on site, the workflows and waterfall aspect of notifications and responses was something that was identified as being receptive to automation in order to mitigate human error in what can be an onerous activity. Automating data collection and processing for other contract administration tasks was another benefit discussed that Intelligent Contracts could potentially perform.

"The link of the BIM data flowing back and forth between the Intelligent Contract would certainly reduce the manpower required to run the same processes manually." AA

Defining risk is tantamount to success in many industries, none more so than in construction. By shifting an organisation to a model-based cost plan, it would allow more effort to be spent on the tendering process which in turn would allow greater definition of risk. The BIM details the project to a far greater level which allows greater confidence in pricing and analysis of risk to avoid rudimentary figures being added by contractors to cover unknown variables. Intelligent Contracts will be more transparent and afford greater determination of risk, therefore making it more straightforward to assign the risk through negotiation. This will simplify negotiations and place parties on a more level playing field. Traditional contract negotiations are facilitated through rigorous back and forth communications, which requires large resources and assumes each party is sophisticated and advanced as each other which is rarely the case.

The automation of the Intelligent Contract will add value and reduce minor dispute. Clash detection in this system would be far superior. An Intelligent Contract forces the execution of the contract. If parties wish to act illegitimately they will have to do so retroactively which of course makes it harder.

By having a more logical and defined dispute procedure that would be initiated automatically and have higher management (or separate teams at the least) handle dispute resolution instead of the site-based teams, greater efficiency and momentum could also be created on projects. This could avoid what can sometimes be emotional negotiations at site level which can exacerbate issues and detract from delivery.

Making the Intelligent Contract act as a central data point that all data flows to, from the BIM model and program schedules etc, will result in the opportunity for real time analysis to take place which allows trends, clashes and potential problems to be flagged early. Intelligent Contracts will ultimately highlight situations earlier as it will rely on pre-agreed logic (at an organisational level) and not individual judgement. In any dispute or grievance, the audibility of data is considered paramount to correctly resolving the situation.

As the Intelligent Contract software will be central to all communications and contractual actions it will be able to provide a concise central auditable ledger of all communications and actions during the lifecycle of any contract. This is already seen in the flux.io workflow software. For larger or more complex projects, blockchain technology could compliment the validity of this process.

While the discussion covered the many merits of the Intelligent Contract process many obstacles for the concept were also raised. Some were obstacles, such as data security and industry confidence, while others were stipulated as pre-cursors required for the technology to operate. Sophistication of the data available was a very evident undercurrent during these interviews as the point of quality outputs being reliant on quality inputs was reinforced time and again.

Separation of sensitive and/or commercial data for ‘bolt-on’ intelligent subcontracts would need to be considered in the data access protocols of any Intelligent Contract in order to maintain data protection.

The automation of contract clauses aren’t the only considerations for the Intelligent Contract. A major hurdle will be in translating and ‘digitising’ the scope of works and specifications in order for it to co-ordinate with the Intelligent Contract protocols. On any projects, these can be extremely complex and have a sheer magnitude of data. This is perhaps where a more advanced BIM evolution would be required as the scope and specs could be mostly taken out of the BIM. Standardisation of specifications and construction methodologies would also help in building a database of acceptable protocols and any amendments for these standards can also be easily updated when they occur, with any consequences captured through analysis. By digitialising the scope as well, clash detection can highlight where there may be contradictions within the contract documents and even shortcomings against legislative standards and specifications.

The extra emphasis and the effort required at the front end of Intelligent Contract projects would also require a cultural shift to having more evolved information early in the construction process. Ultimately, by producing a less complex and convoluted Intelligent Contract which is accepted more as a standard could mitigate this and could eventually speed up the process.

A major point for discussion during all interviews was that the required data to run an Intelligent Contract would go beyond what was potentially available within a BIM model. The consensus that, while BIM could provide data for the physical asset of a design, there are more variables needing to be considered during the construction phase.

The table below shows % of total construction contract value of what is measurable using BIM (note: this is generic and will vary dependant on project requirement) so will range based on an actual project. (Courtesy of Investa Property Group internal company investigation)

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Included/Not Included in 5D BIM measure</th>
<th>%</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Demo, Excavation, site retention</td>
<td>N</td>
<td>10%</td>
<td>5%-10%</td>
</tr>
<tr>
<td>B Trade Works (Materials)</td>
<td>Y</td>
<td>45%</td>
<td>40%-50%</td>
</tr>
<tr>
<td>C Trade Works (Labour)</td>
<td>N</td>
<td>25%</td>
<td>20%-30%</td>
</tr>
<tr>
<td>D Prelims &amp; Supervision</td>
<td>N</td>
<td>13.5%</td>
<td>18%-23% (CBD)</td>
</tr>
<tr>
<td>E Project &amp; Design Management</td>
<td>N</td>
<td>1%</td>
<td></td>
</tr>
<tr>
<td>F Design</td>
<td>N</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>G Margin</td>
<td>N</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100%</td>
<td></td>
</tr>
</tbody>
</table>

From this data, BIM only models ~45% of the total construction cost, so it would not be possible to fully automate claims based on the BIM status against programme alone.

"The BIM model would obviously have to be very sophisticated in that not only components, but also other influencing works be captured and related back to any payment claim from the model." AA

Not only would every element have to be captured but each component/activity/task’s relationship, if any, to other cost items or components in the BIM would need to be considered. Every element could be broken up into procurement, delivery and install to allow stage payments for each cost item if required.

The extra sophistication of not only the BIM data but also the program and cost model will require any contractor to be more transparent due to the reliance on the accuracy of...
the program and BIM model to base payments on. This would be onerous on the contractor which could be an obstacle.

The alignment of payment claims to cost models would result in greater detail needed at the procurement stage. This will again be more onerous for the contractor and one would hope the value in doing so would be realised.

“It builds in a commercial necessity that identifies each task that needs to be carried out for payments to be made.” DR

This is no different to a traditional contract, but an Intelligent Contract will guarantee payment the minute the verification function has been met. This reduces the option for non-payment over a justifiable invoice. Monthly payments could still be maintained but the ‘inch-stone’ tick-off of components will occur more regularly which can give a far clearer picture of any project in a real-time situation.

This is common practice for the contractor to get ahead on cash flow to ‘fund’ the build. Banks are unwilling to release funds with no collateral due to the lack of security over a physical asset that the costs are related to. This is also due to the longer payment terms in the industry. An Intelligent Contract would help by optimising payments and reducing delay which would negate the need for contractors to continue this practice. It will create a more justifiable environment for payment which satisfies the bank and developer while the increase in payment speed would assist the contractor.

Table 1 shows that another factor is data analysis. Once the hurdle of requiring a high level of data capture has been achieved, tremendous value can be added through the analysis of data. Another participant, TT (AEC software developer from Flux technologies), gave an excellent example of what can be achieved through automating a process with high level data and analysis.

“A logistic schedule for structural steel delivery was produced based on where the user placed a crane on the site plan. This was obviously only set up once, so any change from weather or material/construction delay or merely to optimise crane location was able to be done immediately by simply changing parameters in the program.” TT

The value that can be added on to the Intelligent Contract concept through the sophistication of data input it would demand would open the door to endless forecasting opportunities that would add huge efficiency to any project. During all discussions, it became evident that the perception was that BIM has not become the indispensable tool that may be required for the Intelligent concept to succeed.

It seems that, while companies are ‘ticking the box’ of BIM usage for marketing and even some regulatory purposes, it’s true potential is not being harnessed and the goal of the BIM being used in asset operation at a large scale is a long way off yet.

Even when BIM is being used, if only some project stakeholders are involved in the process it negates the advantages BIM even during the design stage where clash detection is achievable. Given that the reputation for innovation is not endemic in the Construction Sector, (McNamara, 2002) it is a shared opinion that the sheer magnitude of the industry makes it difficult for new innovations to be adapted. With that being considered, it is still clear that the attitude towards change and innovation is still lacking. The main driver for implementing any innovation within the industry seems to be more short term focused and demanding of immediate Return On Investment (ROI) in either cost, time or quality.

“For any innovation to be picked up in the construction industry, the benefits have to be very clear. If the benefits are tangible.” HC

Where organisations have implemented innovative practices or technologies, it appears to be the more agile, middle-tier players that have spearheaded change. This insight led to a more widespread discussion about who in the industry would be best placed to champion the Intelligent Contract concept. The opinion that the finance stakeholders in projects would be drivers for Intelligent Contracts due to the opportunity to de-risk the construction process through a more efficient and transparent contract mechanism was not surprising. The upside for a financer of having greater confidence and real-time analysis on the state of a project would mitigate many risks to an investment. The opinion that it developer/contractors would be best placed to implement an Intelligent Contract makes sense due to the openness and transparency of data required for the concept to succeed.

5 Conclusion and further research
The aim of this paper was to investigate the level of collaboration and sophistication of data required from BIM to operate the Intelligent Contract concept successfully through an interview process from a range of senior level construction professionals. The literature review highlighted the deficiencies in the industry’s current contract practices and the need for a new direction to enable collaboration to achieve greater project success throughout the sector. Collaboration has been highlighted time and again as the reason for the success of projects but the current tools and methods are not doing enough to instil this basic principle into the industry. The initial results of this ongoing study highlight that Intelligent Contracts should be the next logical extension to BIM whereby the contractual performance itself becomes automated or even semi-automated in order to address the deficient practice of manual contract administration which can lead to avoidable dispute. The collaboration of all parties with a rich flow of transparent information between them which would offer the right environment for the Intelligent Contract to thrive. However, Intelligent Contracts work best where they are of a short-term nature which is at odds with the complicated and long-running nature of construction projects. As multi-party contracts such as the NEC3 and P2000 offer the ‘hub and spoke’ system of contracts it would offer the organic contract to the next evolution of this model. The logical network of mini contracts would form one seamless organic contract that can offer assurances in one of the largest problems within the construction Industry, certainty of payment. The nature of the Intelligent Contract is that it is an ‘all-in or not-in’ arrangement and through provisions such as a project bank account, or even cryptocurrencies and blockchain technology, the ‘pay when paid’ arrangement would become an instantaneous transaction where all relevant parties are compensated as soon as the terms of the contract are met. There is no delay in the payment ‘dribble down’ effect through contractors to sub-contractors. Discrepancies between scope of the contract clauses would be mitigated due to the bolt on nature of an Intelligent Contract model. This initial research reveals that the automation of contract administration, made possible by linking the Intelligent Contract to BIM would offer accuracy and efficiency:

- The construction schedule could be a real-time tool directly warning of any possible contract issues from real-time data received;
- Variations could be predicted and identified earlier instigating notifications;
- The contract budget could be adjusted automatically and linked to the contract with notifications sent out to facilitate approval.

By offering a different approach that will demand transparency and collaboration therefore de-risking the industry, stakeholder will be able to operate in a more collaborative and transparent fashion leading to global supply chains and gains in efficiencies leading to more certainty over project delivery. In traditional practice, every contractor and sub-contractor and even the client adds contingency to cover risk on
a project which carries a monetary figure. On large projects, this adds up to a huge sum. Due to this level of effort and risk, construction isn't seen as an attractive investment.

The benefits to be made from an Intelligent Contract would be truly disruptive to the contract practice of the sector. Greater administrative efficiency would reduce costs and lead to less minor disputes. Surety of payment would lead to additional small companies being able to operate with confidence in the sector. Transparency of contract terms would drive collaboration and make the industry more attractive to all stakeholders’ due to the greater definition of risk within any project. The input required from all players in the sector would be onerous to make the concept a success. To create an environment where the sophistication of data exists from all stakeholders that will be the fuel for a central Intelligent Contract system, will require a huge step towards the digitisation of the industry. BIM has instigated this, but a tipping point must be reached in order for the industry to surrender to its inevitable switch over to the digital age. The Intelligent Contract will be more than just the reference document that current contracts are used as, it will be a tool to be used central to the construction process.

As the future direction, a phased based approach is the likely road-map and a semi-automated process could be developed using existing contractual procedures. The investigation of what processes in current contractual practices could be optimised through automation will be key to roadmap the path for the incremental steps towards a more automated future. Identification of the processes that would achieve the greatest cost/quality/time saving, while achieving confidence in the process, should make the concept more appetising for the industry.

6 References


Implementation of 360 videos and mobile laser measurement technologies for immersive visualisation of real estate & properties

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Abstract:
Virtual and Augmented Realities (VR & AR) are increasingly utilised in construction and Real Estate industries. Due to the absence of immersive visualisation mechanisms that record the construction process and its defects, the clients can only discover any defects after their purchases. Such discoveries portray a negative image of the real estate agencies as some information may deliberately be held to attract customers who later upon the discoveries of such defects regret their purchase decision. To address these issues, this paper aims at developing and idealizing an immersive visualisation mechanism for buildings using VR based technologies to help post construction sales. The in-construction 3D videos, models and visualisations, made available to the buyers, will help them see the construction quality, workmanship and defects in real time to connect to their buildings and increase their purchase confidence. This paper based on field experimentation using 360 cameras, mobile laser measurement and VR gadgets, collects data from a selected building. Overall, the effects of visualisations on construction site management and processes are explored and a concept of using the data for post-construction sales is presented. The discussions may open avenues for new ideas generations, using the in-construction data to enhance real estate and property sales and address post purchase decision regrets by providing more and detailed information to the customers to make informed decisions. The customers can know about the defects and construction quality beforehand whereas sellers can control construction workmanship thus creating a win-win scenario and promoting trust based mutualistic relation.

Keywords: 360 Camera, Augmented Reality, Innovative Technologies, Mobile Laser Measurement, Real Estate Sales, Virtual Reality, Visualisation.

1 Introduction

The construction industry is a predominately a traditional-bound sector. Recent developments in technology are slowly being diffused into significant construction applications (Howard et al., 2017). VR and AR have revolutionised the way clients and professionals design and visualise their projects (Heinzel et al., 2017). These are increasingly introduced in the Real Estate industry. VR has been termed as a game changer for real estate through increased presence and reach to potential customers by Brenner (2017). Brenner (2017) provides example of a real estate company that provides their own cardboard headsets coupled with their mobile application to provide remote tours to potential buyers to their property. Similarly, AR has been recently used in Real Estate through app for mobile devices, that uses Computer Vision technology for recognizing and tracking planar images and simple 3D objects like boxes and furniture in real-time (Sonje et al., 2018). However, when it comes to real estate sales enhancement while capturing the holistic essence of its customers perception, the applications of VR and AR does not exist. Specifically, most studies show little to no information regarding the property sales process and marketing benefits using VR & AR during the building construction process. This gap is targeted in current study. Such lack of information provision is giving rise to post decision regrets as highlighted by report of Trulia (2017). As per the report, 52% renters and 51% home buyers regret their purchase decision. The main reasons are lack of property information and unsuitability to fit the needs. The issue is that such concerns are realised only after the property is purchased and it is too late to reverse the decision. Therefore, providing enough and detailed information to the customers is the need of the day for making the real estate business sustainable and successful.

VR and AR may side-line the cost of advertising and marketing, which is one of the main costs in Real Estate (Wang et al., 2014). Enhancing property sales with VR and AR visualisation tools may encourage clients to buy more properties and have access to its “under construction” videos and walkthroughs. As the buildings are subject to defects during construction that are concealed during finishing, the buyers are never aware of them unless otherwise exposed during a disastrous event. Using visualisation based during construction videos, the owners will be more aware of their buildings. Further, this will empower the buyers to better understand their buildings with knowledge about the key features such as the plumbing and electrical lines. Not only will it make the maintenance people job easy but also make the buyers more aware and prevent the overcharging by services people. Additionally, the benefit of knowing the building better will help the residents make better purchase, usage, changes and re construction decisions. Keeping these aspects as primary focus, the current study aims at introducing a novel experimental approach for recording building data during construction stage that can be used for post construction sales to provide an immersive environment to the potential occupants to connect to their properties. This will improve the sales and real estate business. For this purpose, the current study makes use of 360 cameras and Mobile Laser Measurement systems.

2 Literature Review

Application of VR and AR within the construction industry has been vastly investigated recently. According to Carter (2017), 87% managers want to improve their communications with tenants. Moreover, the author report that due to misleading advertisements and defects the vacancy rate is as high as 80-90% within the first 10 months of occupancy. Recently Guo et al. (2017) suggest VR and AR safety training lacks interaction, intuition and hands-on training. The authors argue that insufficient safety training leads to incomplete safety planning and invalid site monitoring. Similar to construction, retail sector is also welcoming AR & VR. Poussinek (2018) argues that AR based customer experience help capture their attention and improve their perceptions of the products. AR in retail is used to collect a variety of viewing features that helps integrate a customer’s perception of a product by visualising a three-dimensional display thus enabling an observation from every angle. The author argues that AR should be well-designed to allow practical, easy to use, attractive and relevant information to be provided to the users. Further, a successful AR campaign will generate more sales.

Current head-worn applications allow users and clients to interact with an environment restricted to their access. Wang et al. (2014) consider the extent of VR and AR technology to be limited to the design phase of a project due to the incapability to document onsite progress real-time to achieve the imagery and interaction to take place in real time 3D environment. Projection of displays needs to be developed using 360-degree handheld devices. So far, studies into 360 camera handheld devices are limited to only collecting virtual information from completed construction projects. Azuma et al. (2001) indicates that the use of handheld camera will provide see-through-based video augmentations and visualisations. The use of a handheld device is to solely capture screening on building construction processes.
Marketing in construction and real estate is generally associated with the end-product or pre-construction sale from site plans of larger construction projects. According to Yuen et al. (2011), AR systems can be used to allow designers, workers and clients to walk through a real world site and visualise and experience a building under construction in real time. Such marketing allows users to connect to the project before completion and observe it from multiple locations therefore allowing discovery-based learning. Thus, the potential owners of property will be able to dissect parts of the building construction process to access the information content of interests. According to Musa (2018) advertisement of the construction process enables trust building between contractor and client. According to Park et al. (2013), construction defects are always a key concern of the construction industry that usually occur during the construction process and occupancy stage. As highlighted by Chong and Low (2005) a total of 122 defects were found during the construction phase of a project where 39 of those defects were discovered post completion by occupants. The clients cannot generally discover them unless some event expose it thus visualisation-based marketing can make the clients more aware of the building process and empower to make better decisions. Similarly, Pantano and Servidio (2012) suggest that by utilising visualisation technologies, companies will be able to communicate effectively with their clients. Further, by simulating a unique experience, clients feel physically present because the virtual environment can provide a similar experience that of a real world thus they feel more inclined towards buying the product. Thus, inviting a sense of trust between the construction company and the client will demonstrate a trustworthy connection that may lead to an enhanced property sale.

According to Mahdoujbi et al. (2013), Real Estate sector is largely using conventional methods and techniques for selling properties. The authors argue that the use of technology is developing to take a full advantage of in-house training and adoption of technology-based property advertising. Currently, a limitation of the adoption is the cost of visualisations and lack its usage capabilities and trainings specifically in small to medium enterprises (SMES) and property agents with limited budgets. According to Boga et al. (2018) the drivers towards technological affordability will pave way for stakeholders within the real-estate sector including property developers, agents, homebuyers and investors to benefit from enhanced Real Estate services. Similarly, other drivers for enhanced property sales services are increasing house prices and contractor competitions. As property becomes more expensive, people realise the value for dollar in reviewing property sales in more detail than traditional methods. One of the main costs associated with property sales is that of advertising and marketing (Musa, 2018). Similarly, another limitation of implementing new property selling strategies is the disputes that may be caused due to the inconsistency between the property inspected through virtual reality based visualisations and the real property after purchasing (Wang et al., 2014).

A key concern among Real Estate agencies is the clients’ willingness to buy or purchase intentions and how to improve it (Ullah et al., 2017). Previous studies linked a client’s willingness to buy with the ability to connect with a project. Sonje et al. (2018) also outlined that visualisations through VR and AR are media of generating a compelling sense of presence. Similarly, Pantano et al. (2017) outlined that virtual reality can positively influence the way people acquire product knowledge, attitudes and make purchase intentions. Hence, a client’s willingness to buy is dependent on the quality of the virtual and augmented visualisations. Based on these relevant studies, it can be concluded that the experience generated from the application of VR and AR based visualisations in the building construction process will further enhance potential property sales through a quality marketing approach.

### 3 Research Methodology

The study follows an innovative experimental approach for collecting filed data related to usage of latest technologies in Real Estate and construction domains. The aim is to collect real-life data from case study buildings and visualize them from the perspective of potential clients and users. Similar method has been proposed to be used in construction by Sepasgozar and Shirozvazian (2016) through construction of a framework for conversion of raw 3D point cloud data to compact data. The aim is to update and develop as built models using terrestrial laser scanners. Similarly, in another study, Sepasgozar et al. (2015) utilized a scan station and integrated with as built building information model to collect building 3D point data. In case of Real Estate Industry, Li et al. (2016) has used visualization technique to develop a novel App called HouseSeeker for Melbourne area. It is a visualization-aided system for buyers to help them find, compare and discover various aspects of appropriate properties based on their individual requirements. Similarly, Far and Duarte (2015) has also stressed the importance of visualization based assessment and utilization of conflicted areas in Real Estate for enhanced marketing. Therefore, the researchers designed a case study approach to show features of different digital technologies.

In this study, two innovative technologies have been focused including mobile laser measurement (MLM) and 360° cameras. An experiment each has been performed for the two technologies in Tyree Building (TB) for MLS and two types of 360 cameras. Four data collection areas were chosen on ground level and basement level. The reason for selecting these floors were the presence of natural and artificial light and acceptable level of illuminations. The areas consist of a café and an entrance area on ground level. The café was chosen to show 360° views due to the presence of multiple objects for easier visualizations in case of any defect. Similarly, the entrance area was utilised for estimating errors of MLM measurement (MLM) and 360° cameras. An experiment each has been performed for the two different digital technologies.

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3.1 Utilising 360° cameras for data collection

The first scenario involved the utilisation of two 360 cameras. Firstly, a 360° camera (C1) was used for data collection as shown in Figure 1. An app that can only be used in the smartphones with the same brand of this camera, a data line and a Micro SD card are necessary. The app is for viewing live pictures and revising data. Wearing VR glasses, the videos recorded using 360 cameras were observed from different angles. For this purpose, a VR glass box was utilized that was cell phone compatible. The cell phone can be inserted into the VR glass box and the videos can be observed in real time. The key steps are to import videos and pictures into the smartphone, setting the phone on a VR glass box and using a VR app to control scenes shown in the video. Using the second 360 camera (C2) another experiment was conducted in the same building and floors. Figure 1 also shows parts of the camera and corresponding apps compatible with android and iOS phones.
on as the cell phone to record the correct distance. For greater (b)

Another experiment was conducted in TB using MLM instrument. This instrument can measure real distances and areas in two dimensions (2D) using pictures clicked through smartphones. Thus, constructors may not need to measure distances in dangerous or high-risk areas which can improve construction safety. The MLM consists of a laser scanner that should be in the same orientation as the cell phone to record the correct distance. For greater accuracy it is recommended that the laser scanner is attached to the cell. Other components are the cell phone and a compatible App. Figure 2 shows the required tools and App for using MLM. Once the MLM is integrated, and pictures are clicked, the App provides real time options of measuring the distances and areas in the pictures.

3.2 MLM solution for data collection

There are five different modes in the App of 360° camera each showing scenes in different degrees and angles as shown in Figure 3. The customers can choose any viewing mode to see different zones of target buildings or room easily and clearly. Similarly, the recording route and screenshots of videos of TB in stretched view are shown in Figure 3 (f) and Figure 4 (a) to (f) respectively.

4 Field Experimentation and Results

The innovative tools utilised in current study offer three distinct advantages for field related data collection. These include ease of visualisation, dimensions measurement and time saving.

4.1 Visualising the selected zones

4.2 MLM solution for data collection

Another experiment was conducted in TB using MLM instrument. This instrument can measure real distances and areas in two dimensions (2D) using pictures clicked through smartphones. Thus, constructors may not need to measure distances in dangerous or high-risk areas which can improve construction safety. The MLM consists of a laser scanner that should be in the same orientation as the cell phone to record the correct distance. For greater accuracy it is recommended that the laser scanner is attached to the cell. Other components are the cell phone and a compatible App. Figure 2 shows the required tools and App for using MLM. Once the MLM is integrated, and pictures are clicked, the App provides real time options of measuring the distances and areas in the pictures.

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These screenshots taken at various time intervals are recorded from ground floor to basement floor. Figure 4 shows clear views even in basement levels where the light is usually dim, and views are unclear. Using VR glasses, the customers can walk through the building. This may help sellers to sell more products as customers are more satisfied and immersed due to the playfulness of the instruments. Taking this as an opportunity, the researchers tested the feelings of pedestrians and recorded that they felt interested and satisfied. All the users reported preferring these walkthroughs than watching simple 2D videos. In addition to the elevated good feelings, users and owners can see more details in one scene conveniently without needing to go through many pictures and inspections. For example, they can zoom 360° pictures to see details of buildings like corners and doorframes. An experiment was designed to test the entrance area on ground level. As shown in Figure 5, a monitoring camera and exit and elevator doors can be seen directly in one picture via simple zooming. Thus, the users can see various aspects of the buildings whereas the owners and contractors can know the safety and quality of construction of the building. This creates a win-win situation for all parties.
Additional to customer satisfaction, 360° cameras can help engineers monitor the construction sites with a single one-minute video thereby saving time and ensuring quality construction. A 360° video can be recorded daily to help ensure the desired changes are made and record state of different building parts. This will help ensure construction quality, save cost and time for daily site visits, and record and highlight defects.

4.2 Measuring dimensions during the inspection

A key advantage of using MLM is the dimensions measurement during site inspections. During field experimentation as shown in Figure 7, researchers found that the area of one place on basement level (Figure 4(f): 10.78 square meters) is completely unutilized. It is not used and is a waste in terms of building facilities management. Using similar observations and measurements, engineers can easily find flaws or mismanagement of the facilities quickly with the device during construction process and revise it accordingly. Since all the four corners were perpendicular to each other as marked on the floor, the measured distances in horizontal or vertical direction should be the same. However, there was a huge difference of 1.04 meters in horizontal direction as the measured distances were 3.59 meters and 2.55 meters along the two sides. Thus, an error must exist in the instrument or data collection procedure. After testing many times, the researchers found that the problem is due to the reflectiveness of the surface. As the instrument use laser beam for measuring distances, less reflections and more transparency causes laser beam to be reflected partially or deviate somewhat thereby inducing errors in measurements. Therefore, if the target point is chosen on a surface with low reflectivity or more transparency, results are likely to be inconsistent. To test the accuracy rate of this device and explore the causes of errors, other experiments are conducted accordingly. Study areas include the entrance area (Figure 4 (a)) and space on basement area (Figure 4 (d)).

Table 1 shows the comparison of MLM and traditional measurement method using a measuring tape. X (m) and Y (m) are distances in meters in horizontal and vertical directions respectively. No.1 is the test of object A in Figure 8. Similarly, No.2 and No.3 are tests of Object B. Additionally, No.4 and No.5 are tests of object C. Lastly, No.6 and No.7 are tests of object D. “Time (mn)” in the table is the measuring time in minutes. In this experimentation, results of measuring tape are assumed as real distances because the accuracy of this traditional measurement is high. The equation for assessing errors is used in equation (1).

\[ \text{Relative Error Percentage} = \frac{d_{\text{MLM}} - d_{\text{tape}}}{d_{\text{tape}}} \times 100\% \]  

Where, \(d_{\text{MLM}}\) is the distance measured by MLM and \(d_{\text{tape}}\) is the distance measured by measuring tape. In Table 1 errors of test objects A, B and C are low, whilst those of test object D are high especially in vertical direction. The reason is that first target points of object A, B and C are on surfaces that are more reflective. On the contrary, the target point of D is on a transparent surface with transparent surrounding. Hence the researchers’ assumption of surface reflectiveness playing part in measurement results is verified. The more the reflected light, more accurate will be the results. Besides, comparing object A, B and C, the researchers found the error of object B to be the lowest. This may be due to the ease of marking points on objects. Mark points are the corners of each tested object. As seen in Figure 8, marking points of object B were easy to be pointed on the screen of smartphones, while those of the other two objects were not ideal. Therefore, the points were more approximated in case of the later objects that created errors. Thus, choices of mark points are also very important in these kinds of field experimentation. Table 1 shows errors in measurement using MLM. Specifically, maximum errors exist in the length in vertical direction of object D and errors are minimum in the width of Object B. As discussed previously, the errors may be due to the surface of target point and mark point. If the target point is chosen on a transparent surface like object D, the relative error percentage will be very high. If the control point is easier to find and match in smartphones, measurement will be more accurate such as object B. Thus, low proportion of
transparent areas and good positions of mark points in one scene are necessary to ensure reliable measurement. This enable ease of selecting a target point and the device can receive enough reflected laser beams to measure the distance correctly.

Although accuracy of results of MLM solutions are slightly lower than traditional methods, they are more convenient and can be more widely used. These can test places that measuring tapes cannot, mainly due to the ease of access and less physical labour. For example, in the test of Object B, the height of the door is high that cannot be measured manually without additional tools or ladders, but MLM can achieve the result easily. In addition, MLM can save more time compared with traditional ones. Thus, this kind of technology can help engineers and owners detect distance and area of a building in a very short time only. This will save both time and cost due to quickness and less labour involvement.

5 Technology Comparison for Smart Devices-based Inspections

The devices used for smart technology-based inspections are compared in Table 2. The comparison is carried out based on purchase prices, implementation requirements, ease of use of device, scanning shifts, outcomes and limitations. The four scenarios from (a) to (d) are areas in Figure 4 (b), Figure 6 (d), Figure 7 and Figure 4 (e) respectively. The comparison consists of both types of smart technology devices as well as with a 2D traditional camera. Different cautions are required in each of the four scenarios for using the devices. When recording videos and photos of a corridor and an entrance (Figure 4(a) and 4(b)), surveyors need a tripod to hold 360° cameras. This is because of the area being much populated and used. Further, it is unsafe to put devices on the ground or other open space. As for the space on basement level (Figure 4(c)), a mount is needed to fix 360° cameras on windows due to the viewing requirements. Otherwise people are included in photos that messes the view. Further, setting 360° cameras on the ground with a tripod cannot capture all desired views. The position on windows is ideal for height to record all target objects. The last experimentation is tested on stairs. In this case, it was not ideal to hold 360° cameras to take pictures since it included the researchers and blocked a considerable view. Therefore, the operators need to wait for a time to allow people to pass by and put the cameras on the ground with a tripod to click pictures.

To compare the devices, prices and features are two important factors that needs to be considered. For example, although 360C1 and 360C2 are both 360° cameras, the price of 360C1 is double to that of 360C2. They have different benefits and features thereby one cannot be preferred over the other based on price only. After scrutinizing the collected data, researchers realised that the quality of photos recorded by 360C2 is lower than that of 360C1. However, 360C2 is waterproof while 360C1 is not. Both are clear enough to see outlines and textures of objects in this research, but 360C2 may not be good for other experiments especially whereas the lightning is dim. Thus, researchers may need to estimate and compare them accordingly to select the one suitable for their projects. Additionally, the devices need to be compared based on the scanning and measurement times to judge the suitability for various projects. In this context, a 360° camera is the quickest device for more time saving. MLM devices and traditional 2D cameras consumes much more time to record pictures of a room. Thus, if recording time is vital for a project, a 360° camera may be a better choice though quality of pictures would probably be lower than that of pictures taken by 2D cameras. Similarly, the MLM provides measurement features thus the projects where inspections involve measurements, MLM is a better choice. In conclusion, all digital devices have their own features and useliness. Therefore, it is up to the researchers to choose a device based on the information and data collection requirement.

6 Conclusion and Further Research

This study provides an innovation field experiment-based utilization of smart data collection technologies. Specifically, two technologies: 360 cameras and MLM have been utilized to collect data from a case study building. The result reveal that using these technologies satisfy users and consumers. Based on this information, the potential customers can attain more information (Fig 5) without having to visit the sites daily. for potential customers, the know -how and real time walkthrough-based experience are expected to induce more satisfaction thereby creating more trust required for mutualistic benefits. Such visualisations will give the control to the users to see the information they want instead of what is being fed and provided. This will reduce the need of in person inspections and doubts due to the lack of information provided. Further, it can tackle the deliberate withholding of property information by providing the control to end users and consumers. Based on this information, the potential customers can attain more insights and become more informed thereby making better decisions. This will reduce the post purchase decision regrets as a key cause for that as highlighted by Trulia (2017) is lack of enough information.

This study provides the base for usage of two new innovative technologies for field data collection. It is part of an ongoing study and is currently limited to data collection from an already constructed building. Additionally, the limitations include lack of under construction building study that will be subsequently included as part of the larger research project in

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**Table 2. Comparing the technology-based scenarios for smart inspection with the conventional practice.**

<table>
<thead>
<tr>
<th>Device</th>
<th>Price ($)</th>
<th>Implementation requirements</th>
<th>Ease of use</th>
<th>Scan shifts</th>
<th>Outcomes</th>
<th>Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>360C1</td>
<td>350</td>
<td>App, tripod and smartphone; Few people in scenario (d)</td>
<td>Medium Easy</td>
<td>One time</td>
<td>360° views give customers and engineers more visual information (Fig 5 and 6); Smartphone with the same brand is necessary (Fig 5 (a))</td>
<td>Lower quality of pictures than 2D cameras (Fig 5)</td>
</tr>
<tr>
<td>360C2</td>
<td>150</td>
<td>App, tripod, mount and smartphone</td>
<td>N/A</td>
<td>One time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLM</td>
<td>500</td>
<td>Measuring dimensions and areas in the inspection and save them in the MLM App (Fig 7)</td>
<td>Medium Easy</td>
<td>Several times</td>
<td></td>
<td>More devices required than traditional practice</td>
</tr>
<tr>
<td>Traditional 2D camera</td>
<td>100</td>
<td>Only smartphone</td>
<td>Easy</td>
<td>Several times</td>
<td>Need to use extensive technologies to extract any data</td>
<td>Traditional and outdated</td>
</tr>
</tbody>
</table>


### Exploring potential enhancement of project performance measurement: A process modelling perspective

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**Abstract:**

Project performance management (PPM) is considered a key feature of project management discipline and is one of the most contemporary research topics in the construction industry. However, it can be significantly affected by uncertainties and risks facing the construction project (CP) that in turn can affect project’s time and cost. These risks can be minimised by incorporating learning from previous experience into the PPM. As the whole lifecycle of a construction project has been captured and modelled in various process models, it is argued here that there are values in assessing risks and learning opportunities within the lifecycle of a project, particularly during the pre-construction phases. Various performance assessment models exist and each of them has its own specific characteristics, weaknesses and strengths. This paper forwarded the advantages of assessing risks and learning opportunities in a project, particularly during pre-construction stages and presents a review of various performance assessment models and tools exist in the construction industry. This includes reviewing these PPM model’s characteristics, limitations and strengths to highlight their main features in enabling a more accurate measurement of project’s performance. From this review, Earned Value Method (EVM) has emerged as the most suitable tool, particularly for construction projects. Further discussion review the challenges facing EVM to be used project performance evaluation under uncertain and risky conditions leading to the development of the new research agenda to enhance EVM as the way forward.

**Keywords:**


1 **Introduction**

Planning is a critical part of project management. Substantial work, cost and time are devoted to planning phase so as to assure satisfactory outcomes despite the constraints on budget, time, and other project resources. Project performance is dependent on some factors such as risk conditions, background, financial capability, and resources availabilities (Georgy et al., 2005). Typically, project management tools and techniques monitor the progress of the plan and the actual performance on a regular basis and take corrective actions in case of delay or deviation from the initial schedule to maintain performance. Therefore, the performance assessment and performance prediction are essential to control the project effectively and avoid repetitive errors (Blindebnach-Driessen Van Dalen and Van Den Ende, 2010). In the management system, there is a
significant link between performance assessment methods and effective management (Drucker, 1995) and the value of performance assessment depends on its utilisation.

It has been widely acknowledged that project performance can be significantly affected by risks and the process of learning (Karlsen and Gottschalk, 2004). And construction process is considered involving a very high level of risk so much so that their future performance must be continuously measured and compared against their historical performance so far, i.e. taking into account learning, for the purpose of effective project control (Ezeldin and Sharara, 2006). In looking into learning from earlier stages of the project to minimise risks, there is a need to see the entire project in a holistic manner. As process mapping has been widely accepted as the suitable tools to simplify and model complex processes to allow for more integrated and holistic understanding of the process in a construction project (Tzortzopoulos et al., 2005; Kagioglou et al., 1998), it is argued here that there is a need to assess risks and identify learning opportunities in a construction project by developing a map of the whole project lifecycle. The outcomes of this mapping will then utilised to enhance the existing project performance management (PPM) tools and techniques.

With this in mind, this paper reports the outcome of reviewing existing project performance measurement (PPM) tools and methods in order to find a most suitable method/tool that can be used as the basis for further enhancement. The comparison was based on the ability in measuring performance and providing effective information relevant to the purpose (Poister, 2003). For example the Balanced Score Cards (BSC) (Kaplan and Norton 1993, 1996, 2001), Action Network Process or ANP (Epstein and Westbrook, 2001) were considered suitable for business-wide applications. However, Earned Value Management (EVM) emerged as a suitable method for managing and accessing performance (Anbari, 2003). Therefore, it is recommended here that EVM is to be used as the basis of enhancement in order to develop a holistic PPM method that incorporates risks and learning.

2 The Need for Process Modelling

The appropriate utilisation of the history of contractor’s previous performance in a construction project plays an important role in the success of the project. Within the current mechanisms for contractor selection there has not been any evaluate criteria to demonstrate the capability to identify risks and earn from the past performance of contractor that is critical for the decision on the tender based on these criteria. This identifying and learning capability are increasingly needed as many contractors found that construction projects are getting larger and hence involving more complexity which are significant factors influencing their performance (Aritua et al., 2009).

The process modelling was triggered by various insufficiencies and issues of existing practices in the construction sector stemming from the increasing complexity and hence uncertainties. This has necessitated improvement by comparing and examining best practice in project processes (Rosenau, 1996). It is therefore argued here that by breaking down a process into these components, a more holistic and structured understanding of the process can be developed. The capturing of a process into a more structured understanding is known as process modelling. With the view to better understand construction projects, process modelling has been widely considered suitable to navigate through the dynamics and reduce the complexity of a project environment (Tzortzopoulos et al., 2005; Kagioglou et al., 1998). An example of construction process modelling technique known as the Process Protocol is provided in Figure 1. Each project phase consists of various physical and non-physical tasks guided by the identified project goals and they directly effect on project performance and success (Kao, 2004; Reich et al., 2011). It is stated that considering early stage into the process is the requirement key to minimise both failure and reworking during projects (Kagioglou et al., 1998). According to RIBA’s (2013) four principal phases are applied to classify the process modeling clearly which are pre-project stage, pre-construction stage, construction stage and post-completion stage. It is argued that pre-project and pre-construction stages should be recognised as the most effective stages in securing project long term success (Samset and Volden, 2015). The main key to project success lies in identifying and mitigating challenges during these earlier stages.

From the project performance assessment point of view, managing documentation from a very early stage has a positive impact on project certainty as most aspects will be more manageable and tangible during the early stages (Austeng et al., 2005). This has put the onus on the planner teams to properly define the project at the earlier stages. Furthermore, some scholars have presented that the front-end stage as really critical for ensuring and confirming project achievements and success (Morris, 2013; Merrow, 2011). Miller and Lessard (2000) noted that up to 35% of the project resources and time should be considered and spend on pre-project stage. Morris (2011) also argued that the management of pre-project phases is essential to achieve the project’s desired outcomes. Due to their importance, this study is focusing on the earlier stages of a construction project, particularly pre-project and pre-construction stages in identifying risks and learning opportunities.

Traditional performance measurement techniques do not typically incorporate risks and the learning curve effect, despite the fact that learning is an essential part of any project (Walworth et al., 2016). Despite the widely use of learning models, the learning curve theory has not been extensively used in construction industry. Depending on type of project, learning curve theory can be used as a tool to forecast project cost and time at completion. These important features in the learning curve model can be a major point in the development of classic performance evaluation approaches. Performance evaluation models are discussed briefly below. Following this, the role of the learning curve in assessing the project performance is described also.
3 Method

Research methodology has been defined as the systematic process and specific techniques to analyse and identify information about the topic. Also, it evaluates the study and clarifies two main questions: how was the study analysed and how was the data generated (Iriny and Rose 2005; Kothari, 1985). The research methodology deployed at this stage of research is literature review. This is mainly due to the need for establishing the most suitable PPM method as the basis for the subsequent phase of the research, i.e. to determine a suitable PPM method that can incorporates risks and learning. Basically, literature review has been considered as an evaluative report which highlights and evaluates the essential features of a study. This review summarises and clarifies the strengths and weaknesses of the EVM and describes relevant information and available study around that specific research area. (Brereton et al., 2007; Webster, 2002). So, in this research, literature of PPM and different types of performance measurement methods in construction projects allows for better understanding of PPM methods potentials and highlighting effective role of learning and risk in pre-construction project phase to enhance performance. To do this, a comprehensive review of scholarly papers was implemented in this research. Given that construction projects and the measurement of the performance are challengeable concepts and include various approaches to enhance likelihood of project success (Ankrah and Proverbs, 2005), an extensive literature review was required. So, the following aspects were considered in guiding the focal points of the research to the particular literature study: PPM approaches, performance measurement, EVM implementation, construction process modelling including process protocol.

4 A Review of Performance Measurement Methods

A comprehensive PPM method typically comprises three modules: setting strategic goals, defining performance goals, and designing performance index (Bourne et al., 2000). In the present study, the focus is on developing a holistic PPM method that incorporates risks and learning, the intention here is to establish the most suitable PPM method to be used as the basis for further enhancement. In various projects in the construction and civil industry, data relating to performance focus is mainly on time, resource efforts, and actual cost (Hughes et al., 2004). Different performance measurement methods have been used in construction projects e.g. EVM, Balanced Score Card (BSC), Learning Curve (LC), Analytic Network Process (ANP), and Key Performance Indexes (KPI). A number of previous studies have shown that the learning curve is an appropriate tool to designate the change of project performance (Wong et al. 2007).

Various existing PPM methods used are included in the comparative analysis and presented in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Performance measurement models</th>
<th>Performance indicators</th>
<th>Approach</th>
<th>Learning curve</th>
<th>Risk assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Abran and Buglione, 2003)</td>
<td>BSC</td>
<td>Integration of Quality factor + Economic, Social + Technical dimensions (QEST) and BSC</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(Van Horenbeek and Pintelon, 2014)</td>
<td>analytic network process (ANP)</td>
<td>The value of maintenance, operating costs</td>
<td>Multi-criteria decision-making (MCDM)</td>
<td>-</td>
</tr>
<tr>
<td>(Yahangir and Islam, 2014)</td>
<td>Risk-based BSC</td>
<td>Financial, customer, internal processes, learning, and growth</td>
<td>Conceptual framework</td>
<td>-</td>
</tr>
<tr>
<td>(Malysz and Pem, 2014)</td>
<td>Learning curves</td>
<td>Time and cost</td>
<td>Learning curve prediction model</td>
<td>-</td>
</tr>
<tr>
<td>(Kim, 2015)</td>
<td>EVM</td>
<td>Cost</td>
<td>Cost estimation</td>
<td>-</td>
</tr>
<tr>
<td>(Hu et al., 2015)</td>
<td>BSC and ANP</td>
<td>Knowledge resources</td>
<td>Knowledge performance measurement</td>
<td>-</td>
</tr>
<tr>
<td>(Chen et al., 2016)</td>
<td>EVM</td>
<td>Time and cost</td>
<td>EVM</td>
<td>-</td>
</tr>
<tr>
<td>(Sakka et al., 2016)</td>
<td>Structural equation modeling (SEM)</td>
<td>Project scope and performance</td>
<td>Statistical hypothesis testing</td>
<td>-</td>
</tr>
<tr>
<td>Present study</td>
<td>EVM</td>
<td>Time and cost estimated at completion</td>
<td>Learning curves, curve-fitting models</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 1. The classification of the performance measurement models

<table>
<thead>
<tr>
<th>Performance measurement methods</th>
<th>Strengths</th>
<th>Limitations</th>
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<tbody>
<tr>
<td>Earn Value Management</td>
<td>• With this model, decision maker can measure performance at the right time and prevent potential delays in the project (Mead and El-Sayed, 2016). • Supply and give truthful data and evidence (Richardson, 2015). • The combination of team’s work, cost, and time into manageable part by using Work Breakdown Structure (Richardson, 2015). • Different types of performance indexes such as Schedule (SPI) and Cost (CPI) as an early warning sign for time and anticipate the project final cost (Richardson, 2015). • The Assessment of predicted final cost (Richardson, 2015). • Using regular (e.g., weekly or monthly) Cost Performance Index as a basis and standard (Richardson, 2015).</td>
<td>• Although quality is a vital principle of any projects, it is not examined in this method (Ju and Xu, 2017). • The baseline in EVM is the planned value, and it is considered for calculations and predictions. However, though a factor of unpredictability is involved when doing any anticipations. When this method is done, the project might be on time. However there are some unexpected risks, and based on these risks, it can get delayed in the next steps. Therefore, planned value assumption is not reliable and trustworthy (Chen and Zhang, 2012). • Although, software is necessary, and arrangement between various sections can be really good for achieving goal, managers cannot use this method wildly, because of EVM implementation cost (Chen and Zhang, 2012). • It is a challengeable task for collecting all related data and information to actual cost, and it requires a lot of time for varied and big projects (Chen and Zhang, 2012).</td>
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It is a multi-dimensional method to manage and evaluate efficiency which is particularly connected to organisational approach. The highlight and importance is connecting performance assessment with business unit strategies (Olley, 1999).

In this way, performance evaluation focuses on managing and building relationships between different functional areas (Akkermans and Oorschot, 2002).

Balanced Score Card

- Learning Curve is an efficient tool to monitor the project performance and labours exposed to new work (Anzanello and Fogliatto, 2011).
- Learning curves is an adequate tool to evaluate time needed for completing production and decrease production costs as learning occurs. Also, it has been used to allocate labours to works based on their efficiency profile (Anzanello and Fogliatto, 2011).
- By this method, decision maker is able to find out the complexity of links in the decisions troubles (Van Horenbeek and Pintelon, 2014).
- Key Performance Indexes are collections of data evaluations used to measure the construction operation performance (Cox et al., 2003).
- Also, they use for controlling of pre project phase (Haponava and Al-Jibouri, 2009).

Learning Curve

- Changes in performance data collected in one way may lead to unsustainable learning curve models (Vigil and Sarper, 1994).
- Learning Curve is an unsuitable method for the process specified by the tasks presented to the new and complex tasks. (Mazar and Hastie, 1978).
- In order to correctly recognize the KPIs in relation to the construction procedure, the first step must be a baseline determination. The historical baseline describes a past performance average (Cox et al., 2003).

Analytic Network Process

- Analytic Network Process still trusts on standard pairwise outcomes comparison outcomes among the elements (Sipahi and Timor, 2010).
- In order to correctly recognize the KPIs in relation to the construction procedure, the first step must be a baseline determination. The historical baseline describes a past performance average (Cox et al., 2003).

Key Performance Index

- The considerable weakness in this method is missing of focus on human resources (Malte et al., 2003).
- The problem with BSC’s study is the lack of consensus on what the BSC is about. BSC has various meanings at various times (Ohlman et al., 2006).

As detailed in Tables 1 and 2, most of the traditional performance measurement techniques do not take into account the learning effects, despite the fact that learning has been recognised as a essential part of any project (Walsworth et al., 2016) and that the learning curve is an appropriate tool to model the dynamic behaviour of the contractor’s performance (Jordan et al., 2015; Lee et al., 2015; Wong et al., 2007).

This is mainly because of their qualitative nature (e.g. BSC) or their basic assumption about the constant performance rate (e.g. EVM). On the other hand, a number of previous studies have shown among available performance measurement systems, EVM has been known as an effective method with the capability of predicting outturn costs and duration as well as tracking project progress (Alvarado et al., 2005). Therefore, Earned Value Method (EVM) has a considerable potential to be used as a basic methodology for performance assessment and prediction (Anbari, 2003). Thus, EVM can be used as a powerful performance measurement methodology that has been employed effectively for managing different types of projects.

From the comparative analysis conducted here, it can be argued that EVM is one of the most effective quantitative model for evaluating and controlling the contractors’ performance and potentially the most suitable for the purpose of this research. Therefore, further phase looked deeper into the potential of EVM to be the basis of enhancing PPM method.

Earned value management can theoretically minimise the risk of delay in construction projects by regulating time and cost overruns. EVM is characterised by three elements: budgeted cost of work scheduled (BCWS or currently also referred to as PV) budgeted cost of work accomplished (BCWP or currently also referred to as EV) and actual cost of work performed (ACWP or currently also known as AC). In order to define performance measures, EVM measure performance of budget at completion (BAC), estimate at completion (EAC), schedule variance (SV) and cost variance (CV). Variances to actual and budgeted performance and associated indices have been defined to estimate the final project cost. These basic formulations of the EVM have been provided in equations (1)- (4) and table 3.

<table>
<thead>
<tr>
<th>Performance measure</th>
<th>Formula</th>
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<tr>
<td>EAC</td>
<td>EAC = BAC/CPI</td>
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<tr>
<td>Variance at Completion (VAC)</td>
<td>VAC = BAC - EAC</td>
</tr>
<tr>
<td>Estimate to Complete (ETC)</td>
<td>ETC = EAC - AC</td>
</tr>
<tr>
<td>To Complete Performance Index (TCPi)</td>
<td>TCPi = BAC/EV - BAC/AC</td>
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Typically, substantial learning takes place during initial periods of a project and further literature review revealed that there has been an attempt to enhance EVM in a similar direction to this research. In this regard, Eexlend and Shirar (2006) highlighted the evaluation process and forecasting the performance factor as essential to CPs.

As discussed previously, the learning curve theory has gained growing acceptance as a tool for planning and predicting the behavior of human resource in doing repetitive activities (Jaber, 2016) and depending on the type of project and construction sector, this theory can be used as a tool to forecast project cost and time at completion. Plaza and Turetken (2009) integrated learning curve in EVM to analyse the effects of learning on project performance. These authors developed a decision support to facilitate the calculations of EVM criteria. The proposed methodology was tested in information technology (IT) projects that are affected by learning in the early stages. The outcomes showed that learning curve is a worthy model to assess the project team’s performance.

Despite the growing use of learning models and the dissemination of its benefits, the learning curve theory has not been extensively used in the process of evaluation in the construction industry (Panas and Pantouvakis, 2017). It is underpinned by this untapped potential of learning to enhance evaluation process in construction projects, this research project has been set to enhance EVM as an effective measurement method for project performance.

In the area of learning curve, the learning curve has been introduced by Yelle (1979) to formulate performance changes related to learning. LC is a theoretical model for analysing the nonlinear effects of learning on the performance. Learning curves have been employed in order to forecast the time or cost required to execute a repetitive activity (Malys). Previous research has also recognised a relationship between learning, risk.
and performance. Kumaraswamy (1996) proposed a contractor evaluation and selection model for Hong Kong housing industry. The designed evaluation system is capable of assessing tenders based price and capabilities past performance. Tah and Carr (2001) proposed a risk assessment and control framework in the construction industry. Risk factors were investigated through a hierarchical risk breakdown structure (RBS) that provides a knowledge-oriented methodology to project risk management. Maqood et al., (2006) presented an informational investigation of the learning process in a project through a knowledge management (KM) framework focused on the Australian construction industry. A systematic approach called Soft System Methodology (SSM) was utilised to figure out the knowledge management policies of construction companies. Whilst showing potential, it should be noted that the original EVM models are based on the assumption that the human resources performance is a linear function against time. Thus, EVM outcomes have not taken into account the impact of learning and risk on the project performance indicators. Therefore, the subsequent phases of this research aims to enhance EVM to develop a holistic PPM method that incorporates risks and learning.

5 Conclusion and Further Research

Measuring and enhancing performance represents an important development for improving the CPs efficiency, overcoming various challenges in delivering the projects to optimise performance. This research paper has presented several descriptions and approaches to performance assessment and demonstrated the need for an integrated approach that considers the key elements of learning from prior experiences and risks with the view to enhance projects performance. Whilst appeared to be influential, very few studies have related performance indicators to learning curve under risky conditions. Therefore, this paper has reviewed various performance measurement and identified EVM as the most potential method to be used as the basis for enhancement by incorporating learning and risk in the envisaged framework for a construction project particularly in early project phase. This is an ongoing study considering various factors at different construction stages influencing performance. Therefore, the future direction of this research is to identify the effective factors and their correlation which impact on projects performance and customising EVM as measurement tool to enhance project performance. The findings of the further research are expected to significantly contribute to the project management field by providing an integrated approach supporting the control process and allowing a performance evaluation approach moving from the theoretical background to a more practical one. This will eventually benefit the construction industry by better mitigating risks, increasing efficiency, and reducing project costs.

6 References
