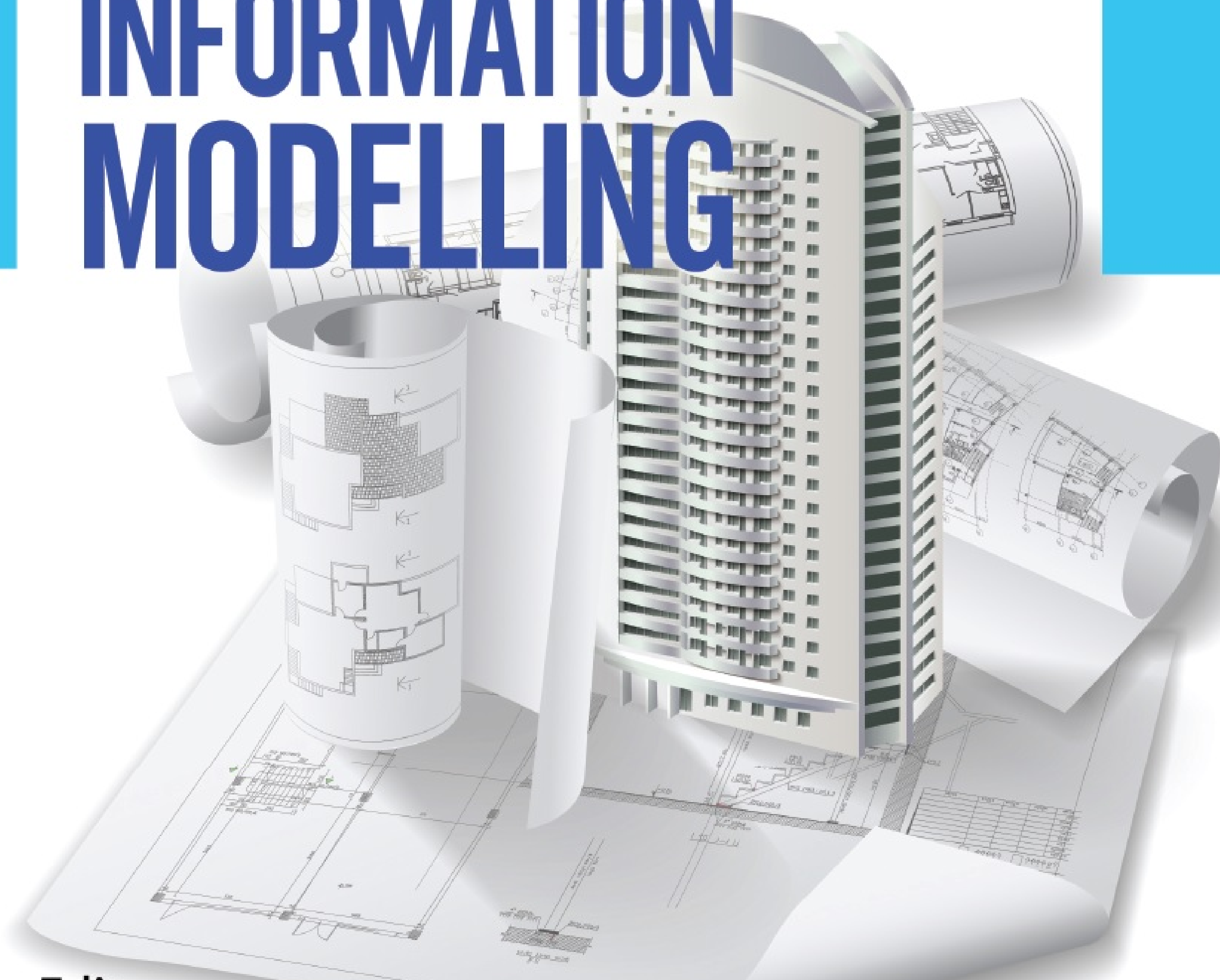
eISBN: 978-1-68108-457-2
ISBN: 978-1-68108-458-9

INTEGRATED BUILDING INFORMATION MODELLING



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Integrated Building Information Modelling

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eISBN (Online): 978-1-68108-457-2

ISBN (Print): 978-1-68108-458-9

First published in 2017.

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FOREWORD

Building information modelling (BIM) is a set of interacting policies, processes and technologies that generates "a methodology to manage the essential building design and project data in digital format throughout the building's life cycle". It makes explicit the interdependency that exists between structure, architectural layout and mechanical, electrical and hydraulic services by technologically coupling project organizations together.

BIM facilitates the convenient and highly-efficient multi-professional collaboration. By synchronizing the central files, various professionals are able to share the same data set and operate on a unified platform. It is noted that the technical kernel of BIM is comprised of 3D visualization and the corresponding building information management mechanisms. With 3D visualization, it is easier to demonstrate design intent of cross-disciplinal professional engineers, and enable intuitive understanding, facilitate timely communication and error checking in drawings. Since large construction projects are featured as large in size, high in interspace and densely-populated, it is easy to cause significant impact to the safety of personnel and loss to property once an emergent situation occurs. Mapping the 3D models of BIM with the intelligent systems can simulate unexpected situations by computer and contingency plans can be made in advance. In addition, utilizing the 3D visualization technology of BIM, the construction unit can publish project construction information and operational information through the internet and other means of mass media. This provides it with a chance of improving the public participation, economic, environmental and the social benefits, as well as other comprehensive benefits.

The present book, structured in 13 chapters, deals with some of the fundamental integrated BIM applications, such as BIM in site layout plan, BIM in construction product management and BIM in hazardous gas monitoring. These chapters demonstrate that BIM is an excellent platform for technology integration.

An overview of the use of BIM is provided to report the best practices, standards, BIM frameworks, manuals and policies from different countries unfolding their status of BIM research, education and industry implementation. While the benefits of BIM, are evident in the past research, these benefits alone may not be sufficient to lead its adoption. An extensive study of the successful BIM cases from across the world, the problems faced and lessons learnt may promote its adoption.

Chapter two reviews the current BIM application and its adoption in housing and investigates an applicable decision support tool to enhance the practicality of housing information modelling in a way that a traditional life cycle assessment (LCA) or life cycle cost (LCC) does not. The case study provided in this chapter demonstrates that what information is required and how data can be developed from stakeholders' requirement in housing construction and management.

Chapter three focuses on investigating the current perceived legal risks as identified by the AEC industry and are used to analyse an existing standard contract to propose changes which will facilitate the transition to a collaborative digital environment. The conceptual model is tested on a standard construction contract (GC21) to test its validity.

Chapter four proposes a final as-built BIM model inspection and management approach when preparing the final as-built model beyond project closeout. The utilization of the proposed approach can effectively manage the status and results of the final as-built BIM model inspection and management work performed. The proposed approach is applied in a selected building case study in Taiwan to verify the proposed approach and to demonstrate the effectiveness of preparing and managing a final as-built BIM model practically. Additionally, this chapter identifies the benefits, limitations, and problems encountered through real cases.

Chapter five summarizes the state-of-the-art in BIM-based methods developed to provides input data to different analyses as well as the state-of-the-art of site layout planning (SLP) optimization models and corresponding solution methods. Benefits to be reaped from integrating BIM within the SLP problem are discussed. Frameworks developed for obtaining travel frequencies and locations of temporary facilities on site, as well as methodologies to account for the dimensions of such facilities at each construction project stage, by taking advantage of the information made available by building information models, project schedules and construction cost databases are presented.

Intelligent and efficient data exchange among various software platforms is the key for sustainable and innovative production systems. The Industry Foundation Classes (IFC) data model is intended to describe building and construction industry data in a standard way which enables various software platforms to exchange information throughout the life cycle of the project with minimum human interaction/ manual data re-entry. Chapter six presents an introduction to the IFC and emphasizes its utility in all the stages of a project by illustrating its application in design, construction and operation & maintenance stage.

Chapter seven provides an organizational level framework with insights into how BIM can be implemented within the construction products manufacturing (CPM) sector to improve solutions at different implementation stages of the AEC sector. The findings of the study push the boundary beyond the fragmented silo style of working between product manufacturing and the construction process, and reveal the new relationships that are formed and the synchronous communication that occurs from the point of object creation through the upload unto the web repository, and ultimately, sharing the product data *via* the project model among the multi-organization project team.

Chapter eight focuses on the implementation of BIM in the construction project management phases and buildings lifecycle covering the ‘asset management'. It aims to argue that integrated BIM usage can be an effective tool in enhancing sustainability and lean performance of construction project management and of asset management.

Chapter nine aims to help the industry understand the current status and future development of BIM-integrated life cycle assessment (LCA). A systematic review shows that BIM has been used as the platform to host LCA implementations for various project life cycles (including production, transportation, construction, operation and end-of-life stages) and environmental impacts (mainly including energy, carbon emissions, water and waste). In addition, future actions are needed in the aspect of standardization, benchmarking and available databases in order to allow accurate comparison of the environmental performance between different projects and design alternatives.

Chapter ten aims to examine the use of BIM in the construction industry and whether it impacts on the key roles and responsibilities of the quantity surveying professional and on construction project cost performance in South Africa. The study concludes that the implementation of BIM technology on construction projects in South Africa will not change the responsibilities and roles of quantity surveyors on projects. It is therefore recommended that South African quantity surveyors use BIM technology on projects to realize the full benefits derived from its implementation internationally.

Chapter eleven provides an overview of the current BIM courses taught in-class and online by the civil engineering department of National Taiwan University (hereinafter referred to as 'NTUCE'). In this chapter, a detailed overview of a basic and foundational in-class BIM course taught at NTUCE, titled "Technology and Application of BIM", and its curriculum with focus on factors such as course objectives, course description, teaching resources used for the course, course contents, teaching methodologies, course discussions, and the evaluation process involved, is provided.

In order to enhance the performance of controlling in hazardous gas detection in underground construction sites, Chapter twelve proposes an solution for the integration of building information modeling (BIM) and wireless sensor networks (WSN) technologies to enable the monitoring of hazardous gas conditions in underground construction site and provides warning signals. It examines the use of the BIM-based safety monitor system to provide the flow of safety information collected by WSN sensors, and visually illustrates the status of detection and alarm regarding hazardous gas with different colors.

Chapter thirteen investigates the prospects and possible challenges confronting the upgradation of BIM technologies in the two leading African economies namely; Nigeria and South Africa. The results will be useful for other developing countries which may wish to implement BIM in the construction industry in the near future.

As a whole, all the fourteen chapters of this book, written by professionals and specialists in the field, offer a valuable review of updated knowledge about the integrated BIM application. All chapters have a large bibliographic reference list which increases their documentary value. The book is of great interest for students, researchers and for those interested in integrated BIM.

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PREFACE

Building Information Modelling, since it was first coined as BIM, has been increasingly acknowledged and accepted all over the world. It now comes to its tipping point for wider and deeper industry practice, therefore, many key practical implementation problems have been spotted and in turn further triggered new research directions. There is a strong need both from BIM industry and academia to be fully aware of the state-of-the-art developments, by doing that successfully, it certainly can further leverage the knowledge from both sides, and eventually could further increase the productivity, performance and efficiency in construction industry.

This edited book intends to leverage the wider BIM knowledge all over the world, both from BIM industry and academia, to provide a comprehensive BIM research and industry implementation picture and future developing roadmap. In this book, there is a team of BIM specialists in UK, USA, New Zealand, Australia and Taiwan who have reported many integrated BIM solutions and future trends of BIM are discussed to create a holistic road map for BIM future.

The editors would like to thank all the authors for their contribution for the publication of:

Integrated Building Information Modelling.

Your commitment and effort in this publication deserves our greatest appreciation.

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CHAPTER 1

Worldwide BIM Overview

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Abstract: The construction sector is one of the oldest sectors of the economy that has played a defining role in the survival of the human race. While it is slow to adopt innovation, the last decade has been marked by an attempt to harness the true potential of increased computing power and information technology products, to make the ground-breaking shift from its traditional Computer Aided Design/Drafting (CADD) approach to an information rich model-based approach. More and more constituents of the industry are shifting towards Building Information Modelling (BIM) that provides such a model-centric way of working. BIM has the potential to positively shift the focus of the industry towards the much needed value-adding tasks, but its holistic implementation is still a challenging task. The BIM process requires that all the industry participants come on board and join hands for effective information management throughout the asset lifecycle and this shift requires an overhaul of the existing (fragmented) practices followed by the individual organizations in their particular sub-domain. The industry as a whole has come to realize that adoption of BIM is crucial for the built environment sector globally as it endeavors to overcome the challenges of environmental sustainability, cost overrun, time delays, and poor quality that are faced by the industry today. This realization is forcing the construction industry to undergo a transformational change in the way work is performed, processed and managed. Although BIM has been identified as an effective solution, its implementation in several parts of the world remains low. The industry requires a well-crafted and well-documented path to increase the productivity, performance, and efficiency *via* the use of BIM. This chapter aims to do this by reporting the global best practices, standards, BIM implementation frameworks, manuals and policies from different countries. Through this, the authors attempt to unfold the status of BIM research, education and industry implementation in major developed and developing markets around the world. At the same time, the chapter also lays out the BIM adoption journey for these countries to allow the readers to understand how BIM implementation takes place over time at the sector level. While the benefits of BIM, are evident in the past research, these benefits alone may not be sufficient to convince stakeholders and encourage adoption. An extensive study of the successful BIM cases from across the world, the problems faced and lessons learned are reported in this chapter to allow the

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readers to develop a deeper understanding of the implementation process and encourage adoption.

Keywords: BIM Research, BIM Implementation, BIM Education, BIM Adoption.

INTRODUCTION

Building Information Modeling (BIM) is a remarkable development that is helping the built environment sector achieve improvements in its processes, practices, and outcomes [1]. It is also helping the sector and its key constituents to review and rethink the way the sector and its constituents function. In a way, BIM is making the industry stakeholders look at every aspect of the functioning of the sector with the aim of propagating systemic improvements. This introspection is possible because BIM has potential implications across all the lifecycle phases of the projects that the industry undertakes. It also influences legal, financial, managerial, technical and social aspects of the industry [2]. Due to this, all specialists within the industry are being forced to introspect their internal work practices, the way they connect with the rest of the project teams, and how they define their roles. This trend is evident in the way industry organizations nationally and internationally are approaching their understanding of BIM, and have been detailing out implementation strategies of BIM.

Although BIM has been identified as an effective solution its implementation in several parts of the world still requires a well-crafted path and a robust strategy to increase the productivity, performance and efficiency gains anticipated by its proponents. This chapter provides a global perspective on these aspects of BIM which are described on a global scale and are woven around the following three major themes:

1. Status of research in the area of BIM
2. State of BIM implementation across major markets
3. Educational initiatives surrounding BIM in major countries

The following sections and subsections provide a snapshot of these three themes as of the last quarter of 2015. These sections rely heavily on published materials freely available for review and do not in any way try to rank or shortlist technologies, software, publications, research groups, *etc*.

STATUS OF RESEARCH IN THE AREA OF BIM

Influence of BIM is now visible in all the aspects of the built environment sector including research and development activities focusing on the sector. A major shift can be seen in the research activities as BIM becomes a new focus of activities, as many researchers are involved in BIM related research directly or indirectly. This shift has been less than a decade old and as recently as 2008 many researchers and practitioners reported the beginning of the "BIM Age" [3]; some marking the beginning of this as late as 2005 [4]. A flurry of activity in the industry and academia around the world surrounding BIM is evident [5, 6]. Research in the area of BIM has been studied by others in the recent past and a trend that shows increased interest in research in this area has been clearly demonstrated [7 - 10]. The following sub-sections trace the evolution of BIM from a research perspective and provide an overview of the current state of the research in this area. Linkages between research and practice are also traced to see how both have evolved.

Evolution of BIM

BIM, the term which has now become ubiquitous in design and construction domain in the past ten years, has disrupted the traditional methods of representation, information sharing, and collaboration. Since, the novel vision of the future architect by Douglas C. Engelbart in 1962 [11], BIM continues to evolve as an effective tool for the industry. Most of the developments in BIM revolve around advancement in computing technology. This trend becomes evident by tracing the historical timeline of research in this area. Leveraging the benefits of increased computing power, BIM has been shown to have the potential to increase the efficiency of the industry by automating complex (generally non-value adding repetitive) tasks and providing a collaborative platform for information generation, sharing and reuse. Historical development in the domain of BIM is shown graphically on a timeline in Fig. (**1**).

The first conceptual understanding of BIM came in 1962 when Engelbart presented his vision of a future architect that was centered around an object-based design approach, parametric manipulation of objects, and a relational database to store objects and associated information [11]. In the following year, Ivan Sutherland developed the sketchpad, an interactive computer-based drawing program, utilizing Semi-Automatic Ground Environment (SAGE) graphical interface [12]. Simultaneously many other researchers started conceptualizing a 'futuristic' design paradigm that revolved around the three-dimensional (3D) design approach and object-orientation. For example, Leifer (1984) developed a concept for the data-rich environment for CADD, which needs to be updated until it uniquely represents the proposed building as shown in Fig. (**2**) [13].

CHAPTER 2

BIM Application and Adoption in the UK Housing Sector

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Abstract: The importance of housing construction and its environmental impact have been argued in the past decades; the increase in housing refurbishment will have significant implications in the UK economy as the residential sector contributes almost a third of total UK construction output and more than 87% of 27.6 million housing stock will still be standing by 2050. Whole house refurbishment seems to be challenging due to the highly fragmented nature of construction practice, which makes the integration of diverse information throughout the project life-cycle difficult. Although Building Information Modelling is becoming increasingly important in the housing sector in order to enhance the practicality of housing construction and management, the current uptake of BIM in housing is very low and there are three main barriers to adopting BIM: business, technical and human problems.

This chapter reviews the current BIM application and its adoption in housing and investigates an applicable decision support tool to enhance the practicality of housing information modelling in a way that a traditional life cycle assessment (LCA) or life cycle cost (LCC) does not. The potential way to integrate both LCA and LCC is suggested in order to measure the environmental and economic impacts of UK affordable housing to seek zero carbon homes. The case study demonstrates that what information is required and how data can be developed from stakeholders' requirement in housing construction and management.

Keywords: Building information modelling, Housing construction, Housing refurbishment, Life cycle assessment, Life cycle cost.

INTRODUCTION

Around 80% of the UK population lives in urban areas, and over 99% of all homes are more than a year old [1]. Out of the stock of 27.6 million homes in

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Table **1** at least 87% of them will still be standing by 2050 with low annual replacement rates of about 0.5% [2]. An ageing housing stock as well as ageing society is of significant interest because older people are major users as well as owners of UK homes, with 57% of them aged 65 or over, reflecting the likelihood that the majority of this group once had mortgages and had paid them off so that they may afford refurbishment. Of those owner-occupiers buying with a mortgage, 63% were in the 35 to 54 age range. Just 10% of all owner-occupiers were aged under 35 [1]. The UK is committed to increasing the number of new houses, 3 million by 2020. However, it is insufficient to replenish the ageing stock and most occupants are faced with refurbishment requirements during the life cycle of owning and using housing. Thus, a substantial increase in the sustainable refurbishment of the existing housing stock is inevitable [3].

Table 1. Population and Housing Stock for the UK.

Area	Population (thousands)	Population density (person per hectare)	Total Housing Stock (thousands)
England	53,012	4.1	22,976
Scotland	5,295	0.7	2,495
Wales	3,063	1.5	1,384
Northern Ireland	1,810	1.3	0,759
UK total	63,182	2.6	27,614

Source: Schmickler and Park [2].

Housing designs have not been built to satisfy whole life requirements, new homes are built to satisfy a capital budget and a performance requirement often at the minimum level, with insufficient attention being given to the whole life costs and performance, ultimately leading to low influence of sustainability. The government's 80% reduction targets in CO_2 emissions by the year 2050 compared to 1990 levels will only be met by a step-change in energy efficiency across all sectors of the UK economy [4]. More than 80% of the building energy is consumed during its operation and maintenance phase of entire building life cycle [5]. As housing energy use accounts for 27% of the UK's CO_2 emissions, which is the major contributor to climate change, the relative importance of embodied CO_2 referred to the energy consumed for building a house keep increasing as new build housing from 2016 is mandated to have zero operation energy and CO_2 emission by the UK government. Since a house usually has 50 to 100 years of life span, it is important to make a considerate decision on selecting refurbishment measures and materials. The housing refurbishment plan should consider how a refurbished house will perform for next decades and what the financial and environmental impacts will be.

The burden of real emissions reduction falls on the existing stock much more heavily than on new house-building due to the current energy performance. It has been estimated 600,000 whole-house refurbishments are needed each year from 2012 in order to achieve this target [6]. It is directly linked to the condition and age of the property.

However, whole house refurbishment seems to be limited due to the highly fragmented nature of construction practice, which makes the integration of diverse information throughout the project life-cycle difficult. Another challenge with this life-cycle approach is that emerging technologies have not always been developed for existing properties, hence making refurbishment and incorporating new technology into existing properties presents a major challenge for the public and private housing sector and it is becoming increasingly difficult to ignore the research demand for the estimating systems focusing on whole life cost and performance for an ageing society, and a rigorous methodology to manage and integrated the massive amount of information among project stakeholders through a project life cycle [7].

As a response to the demand with increasing complexity of construction projects, information and communication technology such as Building Information Modelling (BIM) has been introduced to manage, as well as achieve, sustainability in projects [8]. BIM is currently recognized as an enabler to facilitate collaborative efforts among project participants, and to improve fragmented construction practice and productivity within the Architecture, Engineering, Construction (AEC) and Facility Management industry [9]. Currently, BIM is regarded as a major paradigm shift in the construction industry as it is a catalyst for changes of process and culture that requires more integrated approach than before [10]. The UK government has introduced and promoted BIM in the construction industry, and BIM is mandated to be used for all public projects [11]. Yet, the current uptake of BIM in housing, in particular 'housing refurbishment', is very low although Building Information Modelling is becoming increasingly important and critical in the housing sector in order to enhance the practicality of housing construction and management. Besides, there is no clear energy performance guideline or standard for housing refurbishment, even though there are various energy performance standards for new build housing in terms of the U-value such as Fabric Energy Efficiency Standard and Building Regulation Part L.

Thus, this chapter is to review the current BIM application in the UK and its adoption in the housing sector. Furthermore, the case study is seeking a way in which data in a model can be formatted in BIM context/standards and the best refurbishment solution can be suggested based on the outcome of whole life cycle

CHAPTER 3

An Analysis of the Integration of Building Information Modelling (BIM) in Standard Construction Contracts

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Abstract: Building Information Modelling (BIM) when used in conjunction with a collaborative procurement method promises to overcome many of the redundancies and inefficiencies commonly associated with the construction industry. Despite the promise of increased stakeholder integration and seamless transition of project information, the reality of BIM deployment has thus far been disappointing. Whilst the issues of technological and system compatibility, costs and skill levels are partially responsible, it is frequently noted that existing contractual structures and emerging legal issues also act as barriers to implementation. It remains highly likely that the various standard forms of contract associated with the main construction procurement methods will continue to be used for the foreseeable future, therefore, it is desirable to identify and understand the ways in which conventional contract conditions have the potential to prove inappropriate or counterproductive in a BIM-enabled project environment. This chapter provides a review of the legal barriers and develops a conceptual model for analysing a contract's ability to integrate BIM into the procurement process. The conceptual model is tested on a standard construction contract (GC21) to test its validity.

Keywords: BIM, Contracts, Legal risks, Procurement, Qualitative content analysis.

INTRODUCTION

The emergence of information communication technologies (ICT) tailored specifically for the architectural engineering and construction (AEC) industry has offered one means of improving the information provided to project stakeholders and increase productivity. However, there remains a reluctance within the

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industry to adopt ICT. Building Information Modeling (BIM) is one example of ICT, which has the potential to address a variety of the common criticisms of the AEC sector [1 - 3]. For example, the implementation of BIM can assist in design conceptualization leading to a reduction in the amount of rework and changes during construction, improved project quality and allows for increased levels of prefabrication and offsite construction [4 - 8].

Regardless of the widely acknowledged benefits of BIM, adoption rates and its integration into project delivery models remains low [9,10]. The push towards industry wide BIM adoption has triggered the formation of an array of working groups and government investigations whose aim is to facilitate the transition to a collaborative digital environment. Emerging from these investigations has been the identification of perceived barriers to adoption. One key issue, which has confronted the implementation of BIM, is how the emerging legal and contractual issues will inhibit the comprehensive integration of BIM into the project lifecycle.

The research presented in this chapter focuses on investigating the current perceived legal risks as identified by the AEC industry and are used to analyse an existing standard contract to propose changes which will facilitate the transition to a collaborative digital environment. The research commenced by undertaking a comprehensive review of the existing literature to develop a conceptual framework consisting of ten major legal and contractual concerns. This framework was then used to analyse a standard Australian construction contract, the New South Wales (NSW) Government GC21 2nd edition, and this process identified four key issues which are discussed in length in the final section of this chapter. The chapter starts with a review of the components that underpin the concept of BIM.

BUILDING INFORMATION: THE MODEL, MODELLING AND MANAGEMENT

While the nomenclature and acronym are relatively new to the AEC industry, according to [6], the concepts underpinning the principals of BIM have been around since the early to mid-1960's with its antecedences emerging from the development of Computer Aided Drafting (CAD). The early pioneers of these programs envisaged a far more powerful system than one which simply digitized the drafting and design process, one where a facility could be digitally replicated and could automatically generate the required detail and description of the building or engineering element.

In spite of the term being around since the turn of the twentieth century, a level of confusion still remains as to the actual meaning of BIM [10]. Further, alternative nomenclatures for BIM have been used in the past to describe the same concept.

For example, Building Product Models, nD Modeling, Integrated Design Systems and Object Orientated Building Model. From a theoretical perspective BIM can he separated into three main components or concepts: the Building Information Model; Building Information Modeling; and Building Information Management. Each of these three concepts are described in the following sections based on the definitions from [11].

The Building Information Model

The Building Information Model is defined as a digital representation of the physical and functional characteristics of a facility. The Model can be categorized further into the components of documentation, and graphical and non-graphical information (as shown in Fig. **1**). The Model is generated from the various design disciplines, contractors and subcontractors to create the digital representation. This information is then available to the various project stakeholders to assist in project decision making and may be fed into a central data/repository.

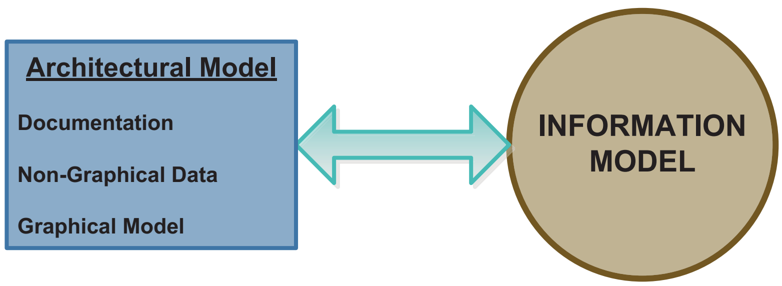

Fig. (1). Building Information Model [(adapted from 11 and 12)].

Building Information Modelling

Building Information Modelling is a business process for generating and leveraging building data in order to design, construct and operate the facility during its lifecycle. The business processes rely on the standardization of information to maintain interoperability between Model authoring systems and analysis software. Information is generated from a combination of BIM analysis and non-graphical information software. Fig. (**2**) graphically represents the Modelling process. In this instance the information pertaining to the architectural components is generated and will reside in the Architectural Model highlighted in blue. Examples of the three subcomponents of the Model could be the contract drawings (documentation) which will be used in the procurement process, meeting minutes and design decisions (non-graphical) and a parametric object based model (graphical model). The arrow represents the transfer of information to the main data repository which is used to transfer other discipline models to enable qualitative project decision making.

CHAPTER 4

A Case Study of Preparing and Managing Final As-Built Model for Owner Beyond Project Closeout

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Abstract: As the application of building information modeling (BIM) becomes more common, BIM model management becomes necessary and important to enhance the effectiveness of BIM implementation during the construction phase. The completeness and accuracy of a final as-built model is necessary and important for a general contractor (GC) beyond project closeout. BIM model inspection (BMI) is one of the major works executed by GCs for the completeness and accuracy of a final as-built model. Furthermore, final as-built BIM model management is now recognized as the most critical BIM management strategy in construction management. However, there are many problems in a final as-built model that exist in practice because of a final as-built model mismatch, the lack of final as-built models, and incorrect information entry of final as-built models. In order to solve the problems, this chapter proposes a final as-built BIM model inspection and management approach when preparing the final as-built model beyond project closeout. The utilization of the proposed approach can effectively manage the status and results of the final as-built BIM model inspection and management work performed. The proposed approach was applied in a selected building case study in Taiwan to verify our proposed approach and to demonstrate the effectiveness of preparing and managing a final as-built BIM model practically. Additionally, this chapter identifies the benefits, limitations, and problems encountered through real cases. Finally, conclusion and suggestions are summarized for further applications. We expect the effective use of the proposed approach to significantly help GCs to handle the final as-built BIM model inspection and management work effectively for the owner beyond project closeout.

Keywords: Building information modeling, BIM, BIM management Construction management, Final as-built model.

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INTRODUCTION

As the application of building information modeling (BIM) becomes more common, the utilization of BIM becomes necessary and important to enhance the effectiveness of BIM implementation during the construction phase. The completeness and accuracy of a final as-built BIM model is necessary and important for the GC beyond project closeout. BIM model inspection (BMI) is one of the major works executed by GCs for the completeness and accuracy of a final as-built model. Furthermore, final as-built BIM model management is now recognized as the most critical BIM management strategy in construction management. Recently, the adoption of BIM application has increased during the construction phase in Taiwan. Most of the GCs expect that BIM can be utilized effectively to enhance the performance of construction management during the construction phase, as well as view and access the progress in the building by use of a computer prior to its actual construction. However, the evolution impacts not only the previous approach to and execution of the physical design of a building, but also the management of its construction.

It is necessary and important for the GC to ensure the accuracy of the as-built BIM model beyond project closeout to allow the owner to apply the as-built BIM model in facility management during the operation and maintenance phase. If the owner lacks trust in the accuracy of the BIM model, it jeopardizes the owner's willingness to employ as-built model in facility management. Consequently, the implementation of construction management integrated with BIM in practice will fail if it lacks the support of owner upper management. Therefore, this chapter proposes a final as-built BIM model inspection and management approach when preparing the final as-built model beyond project closeout.

In Taiwan, level of development (LOD) of the BIM model is selected as a major BIM inspection standard in the contract. However, there may be confusion between owner and general contractor about the final as-built BIM model inspection process. It is necessary and important for the GC to reduce problems of confusion regarding the final as-built BIM model work. Therefore, the main purposes of this work are as follows: (1) identify the major practical problems regarding the final as-built BIM models work beyond project closeout; (2) propose a framework and documents for accepting the final as-built BIM models inspection and correction work; and, (3) enable BIM engineers and field engineers to track and manage the status of revised final as-built models effectively. Furthermore, the proposed approach is applied in a real case involving a Taiwan commerce building project to verify the proposed methodology.. Given appropriate modifications, the final as-built model management approach can be implemented e by the GCs to demonstrate the effectiveness of the final as-built model management.

BACKGROUND

Building Information Modeling (BIM) is one of the most promising developments in the construction industries. The concept was derived from the GC to purpose building description systems [1]. In recent years, BIM technology developed quickly due to the advent of computer technology that has become more powerful. BIM differs from 2D and 3D computer-aided design (CAD) and is changing how buildings, infrastructure, and utilities are planned, designed, built, and managed. When adopted well, BIM facilitates a more integrated design and construction process that results in better quality buildings at a lower cost and reduced project duration.

There is very limited research work addressing the final as-built BIM model inspection and management issues specifically within the construction project management context [1, 2] proposed using a laser scanner and a camera to capture the construction history and develop a more complete as-built BIM. The extensive as-built BIM updates the as-designed BIM to coincide with the construction changes [3] developed a web ConBIM-SM system for the GC in order to enhance visual as-built schedule information sharing and efficiency to track the construction as-built schedule [4] utilized BIM technology to model heritage building. There are three fundamental steps - acquisition, segmentation and modeling - that are used to create such a well-structured and enriched 3D digital model. This paper endeavors to define a new semantic structuring approach, taking into account the complexity of this chain, and proposes a survey on these topics [4]. In order to solve critical issues [5], used scan point clouds to incur the as-built BIM creation of building interiors. The approach was shown to be a more practical semi-automated methodology for improved productivity of as-built BIM creation with respect to large and complex indoor environments [6]. discussed fully automated as-built BIM creation management, albeit difficult since newly constructed buildings are becoming more complex. Therefore, this research group has developed a semi-automated approach, focusing on a productive 3D as-built BIM creation for complex indoor environments. The test feasibility is by application of the developed approach with the case study in Korea [7] described an approach for developing as-built BIM coupled with various data acquisition tools. Existing as-built technologies, such as 3D laser scanning, are reviewed, and future uses for as-built BIM are suggested [8] reviewed previous research in automated code compliance. The research identifies key issues for future development and examines the causes of information paucity for compliance checking in the current generation of BIM tools [9] developed an overview of concepts for BIM model checking. This paper will discuss a mixed use of these

CHAPTER 5

Estimation of Input Parameters Used in Site Layout Planning through Integration of BIM, Project Schedules, Geographic Information Systems and Cost Databases

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Abstract: While site layout planning (SLP) has been widely investigated in the literature, little attention has been directed towards improving the precision of the input parameters required by the SLP optimisation models. The main input parameters required in a dynamic site layout model are the travel frequencies between different facilities, the spatial coordinates of permanent facilities, candidate locations for temporary facilities and facility dimensions. Obtaining reasonable estimates of these parameters is challenging when a dynamic site environment is considered. The estimation process entails a realistic evaluation of: 1). the quantities of material to be transported between facilities at each stage of the construction process; 2). the coordinate positioning of permanent facilities; and 3). the dimensions of the temporary facilities to be positioned. This necessitates the utilisation of information on the progress of different activities and their corresponding material demands and associated facilities during each construction stage. The increasing adoption of building information modelling (BIM) in projects and the resulting extensive project database made available by BIM has provided unique opportunities to improve the accuracy of such assessments. This chapter discusses the applications of BIM in SLP. The chapter starts by discussing the composition of a typical SLP problem and the importance of obtaining reasonable estimates for its associated parameters. The chapter continues by summarising the state-of-the-art in BIM-based methods developed to provide input data to different analyses as well as the state-of-the-art of SLP optimisation models and corresponding solution methods. Benefits to be reaped from integrating BIM within the SLP problem are discussed. Frameworks developed for obtaining travel frequencies and locations of temporary facilities on site, as well as methodologies to account for the dimensions of such facilities at each construction project stage, by taking advantage of the information made available by building information models, project schedules and construction cost databases are presented. The results obtained through applications of one of the proposed frameworks to an illustrative case study highlight the capabilities offered by adopting BIM in SLP.

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Keywords: BIM and schedule integration, Integrated building information modelling, Mixed integer programming, Optimisation, Site layout planning, Travel frequency.

INTRODUCTION

The progressive nature of construction projects presents a scope for applications of tools that provide the users/decision makers with the ability to envisage the step-by-step evolution of the project on-hand. Imperative facets in construction projects such as collision and clash detection, site safety improvement, progressive task monitoring and control, stage-to-stage planning, and the necessity to visualise a project's construction procedure before the actual construction starts, led to the adoption of Building Information Modelling (BIM) [1 - 3]. The ability of the user to conjure up an overview of the actual construction environment during different stages of the project's construction phase provides valuable means in terms of ensuring a smooth and well-managed set up of the initial project planning strategies. Innovations in the area of high dimension visualisation have also played a key role in advocating the use of BIM in progressive environments applicable to the nature of a construction site [4]. While the adoption of BIM was initially advocated by placing the focus on its unique visualisation capabilities, recently the focus has been partly shifted to its use for integrated design applications, planning and evaluation, where BIM serves as a comprehensive database, and pre-processing various analyses required during the planning and the implementation of construction projects [5].

One of the areas that occupy high relevance when it comes to setting out the initial work task plans across a project's duration is the site layout configuration utilised [6]. Laying out a construction site involves the allocation of various operating facilities to the space available during construction [7]. The necessary decisions in such a process are influenced by the total space available, which is directly related to the construction stage being implemented. In the context of this decision-making process, a description of possible avenues and benefits from applications of BIM in the planning aspect of site layouts is highlighted in this work.

This chapter presents as overview of the use of BIM in the various planning phases of projects. Efforts are concentrated mainly on information that can be extracted from generated building models and linked to other platforms to enable additional processing. Particular emphasis is placed on the applicability of BIM in Site Layout Planning (SLP), given that this is an area which results in a high level of influence on the overall structure of work tasks carried out on a construction site [8]. The aim of the chapter is to therefore showcase the benefits to be reaped from deploying 3-D visualisation tools such as BIM in the realm of SLP for initial construction plan set-ups.

ESTIMATION OF INPUT PARAMETERS REQUIRED IN PLANNING AND EVALUATION USING BIM – A REVIEW

Through the utilisation of BIM, the ability to embed semantic information regarding the building elements involved is made possible. The representation rendered by BIM is a 3-D geometrical depiction of linked building elements [9]. Fig. (**1**) shows the relationship between individual components of a building that is formed through a 3-D framework. When a schedule of work is incorporated so that temporal depictions can be rendered, the representation is then described as a 4th dimensional illustration [10]. This is shown again in Fig. (**1**). A higher dimensional representation can also result, namely 5-D, and this involves incorporating cost related information to the 4-D model described previously [11]. The possibilities of inter-relating BIM with various other platforms for organisational purposes have been highlighted in the literature [12].

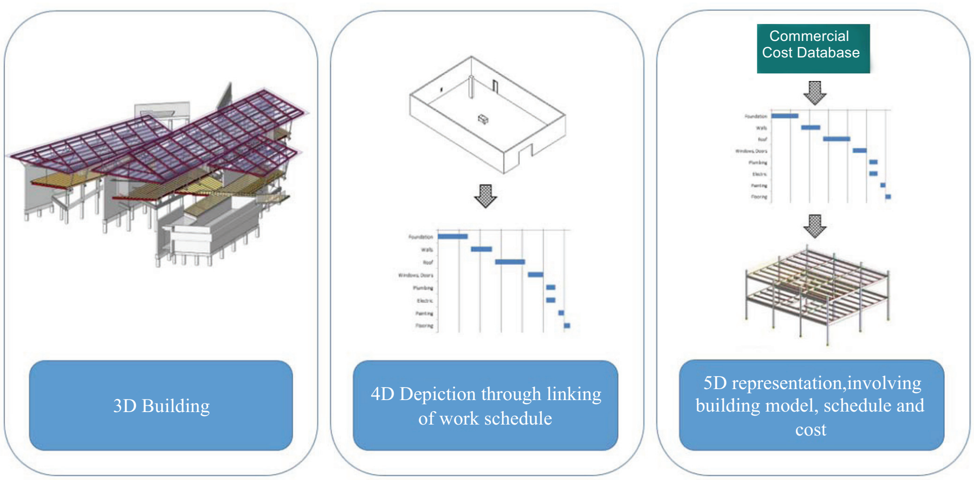

Fig. (1). Possible dimensional representations through the linking of various informational constituents.

The ever expanding interest in the adoption of virtual modelling techniques in the construction industry is evident when one views the corresponding body of literature presented. Applications focus mainly on deploying BIM for the purpose of acquiring input data which will then undergo additional processing to achieve the final results. Fig. (**2**) depicts the stretch of appositeness of BIM in construction. Within the area of sustainable design and development an approach has been proposed by Azhar and co-workers [1] where a framework is presented

CHAPTER 6

A Review of Industry Foundation Class (IFC) Based Data Exchange Model

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Abstract: Complexity in today's construction projects necessitate comprehensive proficiency in various divergent domains. These domain-specific professionals usually work with software solutions that are highly specialized which often do not provide adequate means of data exchange with other software products. However, the building industry has collaborative atmosphere that involves repeated, iterative data exchanges and communication. To automate information processing there is a need of standardized and qualified data for efficient working processes. IFC provides vendor-independent and open building information models to capture and exchange data. This chapter presents an introduction to the IFC and emphasizes its utility in all the stages of a project by illustrating its application in design, construction and operation & maintenance stage.

Keywords: BEM, Compliance checking, Cost estimation, IFC, Progress monitoring, RFID, Work space management.

INTRODUCTION

Intelligent and efficient data exchange among various software platforms is the key for sustainable and innovative production systems. The Industry Foundation Classes (IFC) data model is intended to describe building and construction industry data in a standard way which enables various software platforms to exchange information throughout the life cycle of the project with minimum human interaction/ manual data re-entry. A review of the standards surrounding the data management protocols in construction industry is essential to put things in perspective.

Building SMART (formerly the International Alliance for Interoperability, IAI) is the worldwide authority driving transformation of the built environment through

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creation and adoption of open, international standards. This organization lays out five basic standards for data management [1]:

1. Process Standard – Information Delivery Manual (IDM): BuildingSMART processes (IDMs) encompass (and gradually incorporate) business process whilst at the same time providing comprehensive specifications of the information that a user satisfying a specific role would need to deliver at a certain point within a project.
2. Data Standard – Industry Foundation Class (IFC): Different project team members employ various different software solutions during design, construction, procurement, maintenance and operations. This standard ensures proper data sharing across these software applications.
3. Change Coordination – BIM Collaboration Format (BCF): BCF is a streamlined open standard XML schema that encrypts messages to allow workflow communication amongst different BIM software tools.
4. Mapping of Terms – International Framework for Dictionaries (IFD): The buildingSMART Data Dictionary (bSDD) is a reference library grounded on the IFD standard and envisioned to back enhanced interoperability in the building and construction industry. The bSDD delivers a flexible and strong method of linking prevailing databases with construction information to a BIM model.
5. Process Translation – Model View Definition (MVD): It defines the division of the IFC data model that is essential to support the explicit data exchange necessities of the AEC industry throughout the life-cycle of a construction project. A MVD delivers application guidance (or application agreements) for all IFC concepts (classes, attributes, relationships, property sets, quantity definitions, *etc*.) used within a specific subset.

IFC

In 1994 Autodesk constituted an industry group to guide the company on the expansion of a set of C++ classes that could support integrated application development. Initially named the Industry Alliance for Interoperability and altered its title in 1997 to the International Alliance for Interoperability. The new Alliance was re-formed as a no profit industry managed organization, with the objective of distributing the Industry Foundation Class (IFC) as a neutral AEC product model answering to the AEC building lifecycle. An additional name alteration happened in 2005, and the IFC specification is currently managed by buildingSMART [2]. The first IFC model (IFC 1.0) was published in January 1997 and an addendum to the latest release (IFC4 Add1) is published in July 2015. IFC describes multiple file formats that may be used, associating various encodings of the similar underlying data [3]:

1. IFC-SPF is a text format defined by ISO 10303-21 (“STEP-File”), where each line typically consists of a single object record, and having file extension “.ifc”. This is the most widely used IFC format, having the advantage of compact size yet readable text.
2. IFC-XML is an XML format defined by ISO 10303-28 (“STEP-XML”), having file extension “.ifcXML”. This format is suitable for interoperability with XML tools and exchanging partial building models. Due to the large size of typical building models, this format is less common in practice.
3. IFC-ZIP is a ZIP compressed format consisting of an embedded IFC-SPF file and having file extension “.ifcZIP”.

IFC has four layers, IFC 2x consists of the (i) Resource Layer, (ii) Core Layer with Kernel & Extensions, (iii) Interoperability Layer and (iv) Domain Layer. A detail of the contents is provided in the Table **1** below which is adapted from BuildingSmart Chapters [4]. Building geometry and material property information can be exported to the standard format such as the IFC compliant STEP (Standard for Exchange of Product Model Data) physical data file (ISO 10303-21) from a BIM authoring tool by using IFC data model. STEP physical file has a header section and a data section; the header section contains information about the company, name, authorizing person, time and date when the export was done, IFC version used, the application that exported the file *etc*. The data section contains all occurrences for the entities of the IFC specification. These occurrences have a distinctive (within the scope of a file) STEP Id, the entity type name and a list of explicit attribute [5]. IFC describes an EXPRESS based entity-relationship model consisting of hundreds of entities ordered into an object-based heritage hierarchy. Examples of entities comprise of basic constructs such as IfcCartesianPoint, geometry such as IfcExtrudedAreaSolid and building elements such as IfcWall. The main division of IFC entities is into rooted and non-rooted entities. This division is based on the concept of identity (having a GUID). Rooted entities have identity along with attributes for name, description, and revision control when the non-rooted only exist if referenced from a rooted instance directly or indirectly. Three abstract concepts further subdivide the IfcRoot: object definitions, relationships, and property sets:

- IfcObjectDefinition captures tangible object occurrences and types
- IfcRelationship captures relationships among objects
- IfcPropertyDefinition captures dynamically extensible properties about objects

A detailed illustration of the above mentioned instances can be accessed here: http://www.buildingsmart-tech.org/ifc/IFC4x1/html/

CHAPTER 7

Exploring the Deployment of Building Information Modelling (BIM) for Construction Products Management

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Abstract: The architecture, engineering, and construction (AEC) sector is currently faced with enormous technological and institutional transformations across the design, construction and operation stages of a project. One very important instrument to such change is the rapid pace of BIM deployment with its resultant challenges. Indeed, the BIM work processes vary across discipline, thus creating a new dramatic requirement for the way in which product data is produced, integrated and shared across the supply chain. This particularly places an unusual responsibility on the building product manufacturing sector. There has been a plethora of research on BIM adoption within construction and design practices. Not much research has been done on utilising BIM for construction products management (CPM). Research from recent case study with a construction product manufacturer provides useful insight and practical experience on lessons learnt which may be valuable in other similar contexts.

The research results provide an organizational level framework with insights into how BIM can be implemented within the construction products manufacturing (CPM) sector to improve solutions at different implementation stages of the AEC sector. The findings of the study push the boundary beyond the fragmented silo style of working between product manufacturing and the construction process, and reveal the new relationships that are formed and the synchronous communication that occurs from the point of object creation through the upload unto the web repository, and ultimately, sharing the product data *via* the project model among the multi-organisation project team.

Keywords: Building information modelling, Construction products, Semantic web, Object repositories, Proprietary objects.

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INTRODUCTION

It seems that there is a widespread consensus among the practitioners in the AEC industry and among scholars about the necessity to augment the utilisation of BIM within the construction industry [1, 2]. The vision of using BIM as a response to the construction industry's challenges is not only articulated by construction practitioners and academics, but also, is embraced by governments through the development of roadmaps for the specific purpose of facilitating research and development of BIM for the construction industry [3, 4]. As G. Aranda-Mena *etal* [5] suggests, the premise is that BIM is not an option but an emerging order for the AEC sector. Thus, it is paramount to develop the requisite knowledge across the sector and the appropriate timing for the transitional shift by organisations that deem it relevant.

Despite the alluring implementation promises, effective management of the deployment processes seems fraught with challenges for key policy and decision makers. Full exploitation of BIM on a typical project requires clients, consultants, contractors, product makers and facilities managers to participate in the digital process. This is because, a rapport between these seemingly disparate, yet interconnected sector organisations [6] is necessary for managing the interfaces between them to achieve that needed integration of design, construction and operation of a facility. However, R.G. Saxon [7] has identified that these sector organisations need to change their existing conventional work plans and business models in order to exploit BIM more fully. BIM-enabled work practices have proven to be difficult and most organisations have been unable to adjust their work practices to favour the BIM mode [8]. The construction product manufacturing (CPM) sector is no exception. While BIM has been receiving increasing attention in the design and construction phase of projects, less attention has been given to the deployment of BIM in promoting construction product management for the benefit of the entire AEC sector. A working group concerned with the rollout of BIM to support construction products manufacturers has recently published a research report focusing on knowledge capability of the sector to deliver digital product information [9]. The report highlights how BIM investment decisions can benefit manufacturing organisations and more importantly that, consensus was still needed in order to promote and leverage BIM synergy through processes and systems within the CPM sector. To do this, some knowledge building is required, even among those that have launched their own BIM contents [9].

This paper therefore concentrates on bridging the knowledge gap in BIM deployment within the construction products sector. The aim of this paper is to investigate the organizational processes associated with the deployment of BIM for construction products management. In particular, it provides an insight into how specific issues of CPM influence organisation decision making on BIM rollout. The first part of the paper reviews relevant literature on the current state of knowledge on the deployment of BIM for construction products management. This review informed the development of the research and data collection strategy from the case organization. The second part of the paper presents the analysis, and discusses the results and findings of the case study.

Overview of the Construction Products Management Sector

Offsite Manufacturing (OSM), Off-site Production (OSP) and Construction Products Manufacturing (CPM) are all generic terms that have been used interchangeably in extant literature to describe forms of moving onsite production into manufacturing facilities where construction products and components are prefabricated within a controlled environment [10, 11]. CPM is increasingly promoted owing to its potential benefits such as faster construction process, cleaner and safer working environment and better quality end product compared to the traditional construction process [12]. The European Union entity on regulating construction products has defined construction products as "any product or kit which is produced and placed on the market for incorporation in a permanent manner in construction works or parts thereof and the performance of which has an effect on the performance of the construction works with respect to the basic requirements for construction works" [13]. The CPM sector could potentially be regarded as a powerhouse within the AEC organization. The turnover of the European construction product manufacturers was estimated at 360 billion Euros in 2009, and the number of employees was 2.6 million [14]. Further, most construction innovations originate from component producers who have vested interests in construction products and thus, invest large amount of resources into its research and development [15, 16]. Construction products or components form a large percentage of objects in a typical building model. Because they represent both the graphical and non-graphical data, the objects of construction products play a very important role in the successful rollout of BIM across the design, construction and operation of a facility [17].

Despite the surge in the number of proprietary objects developers, most building modellers still rely on generic objects in the BIM platform to develop their models. In a survey on where BIM users get their BIM contents from for their models, only 19% get their contents from objects libraries either all or most of the time, and about 50% most of the time build their model with the generic objects in their software [17]. Further research is therefore required on how construction product manufacturers can leverage BIM to comprehensively support proprietary objects development, management and integration into the project-delivery cycle.

CHAPTER 8

Integrated BIM Usage in Construction Project Management: As a Way of Enhancing Sustainability and Lean Performance of Construction Industry

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Abstract: The climate is changing, and the Earth's resources are being exploited. According to the latest report by the United Nations scientific panel on climate change, collective and significant global action is needed to reduce greenhouse gas emissions and to keep global warming below 2°C (EC website, 2014). As the environmental degradation continues to occur in an accelerated way, time is of the essence for taking effective precautions. Due to its inputs, outputs, and the construction process, the construction industry can adversely affect the environment. Enhancing lean and sustainability performance of the construction industry can contribute to the reduction of the construction industry's footprint. Integrated BIM usage can be an effective tool in enhancing sustainability and lean performance of construction project management and of asset management. Based on an in-depth literature review, this chapter focuses on the implementation of BIM in the construction project management phases and buildings' lifecycle covering the 'asset management'. This chapter is expected to enhance the literature especially with its scope and holistic view.

Keywords: BIM, Construction project management, Lean and agile project management, Sustainability.

INTRODUCTION

BIM is a data model enabling data interoperability [1] (p. 197). "BIM is a digital representation of a building, an object-oriented three-dimensional model, or a repository of project information to facilitate interoperability and exchange of information with related software applications" [2] (p. 84). In other words, BIM can be defined as "a shared database for the project, assigned to the 3D model of the object, based on which a complete project documentation can be built" [3]

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(p. 212). BIM enables spatial visualization, simulation of the behavior of the building, as well as more efficient project management [2] (p.84). There are various definitions of the BIM as provided in Table **1**.

Table 1. BIM definitions.

BIM is "a process focused on the development, use and transfer of a digital information model of a building project to improve the design, construction and operations of a project or portfolio of facilities."	[4] (p. 1)
BIM is "a digital representation of physical and functional characteristics of a facility...and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition."	[5]
BIM is a "process of designing, constructing or operating a building or infrastructure asset using electronic object-oriented information"	[6] (p. 3)
BIM is "the development and use of a multi-faceted computer software data model to not only document a building design, but to simulate the construction and operation of a new capital facility or a recapitalized (modernized) facility."	[7]

BIM has different dimensions based on the functionality it covers (Fig. **1**). BIM 3D covers virtual 3D parametric model. BIM 4D can be described as the BIM 3D covering scheduling function. BIM 5D provides all functions provided by the BIM 4D plus the estimating function. BIM 6D provides the functions of the BIM 5D plus the sustainability-related functions. BIM 7D provides all functions of the BIM 6D plus the facilities management function. Different BIM dimensions enable BIM models to be used throughout the building or other construction's lifecycle [8].

The idea of BIM emerged four decades ago. Researchers recognized the need for an interoperable software in the 1970s and they have started to work on "integrated design databases" [9] or "integrated design systems" [10, 11] (p. 12). The development of the ArchiCAD software program in 1982, and the development of the Revit software program in 2000 can be seen as the foundations of BIM [12]. The usage of BIM has been widespread due to the benefits of BIM implementation and countries' encouraging policies. There is an acceleration in BIM implementation [13] (p. 483). McGraw Hill's [14] research on the evolution and worldwide implementation of BIM revealed the increase in the BIM usage trend (*e.g.* in North America BIM adoption by contractors escalated from 28% in 2007 to 71% in 2012) [15] (p. 1145). As projects' complexity and requirements have been increased and the schedules have become tight [16], the need for more interactive collaboration among the project team members has been increased [17] (p. 533).

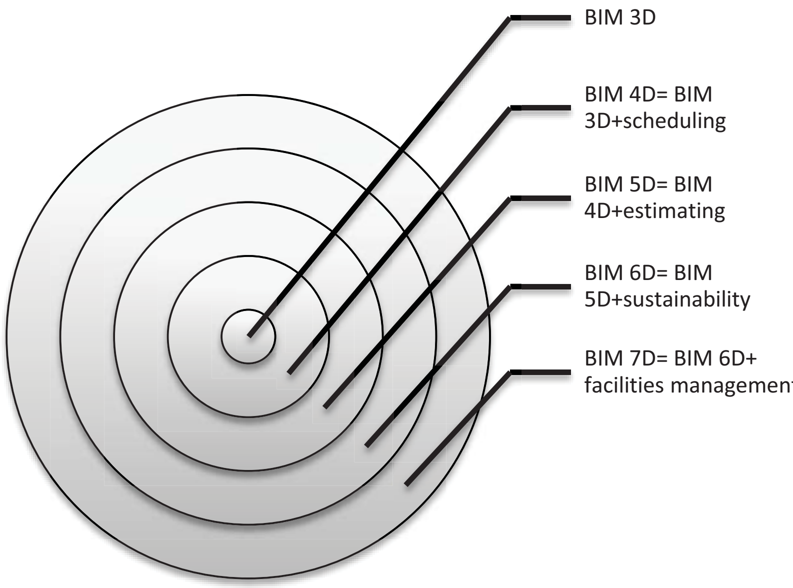

Fig. (1). BIM dimensions (adapted from [3] (p. 212-213).

Competitive nature of the construction industry and construction industry's concern to enhance productivity [18] (pp. 19–25), as well as the need for reducing the construction industry's environmental footprint, have fostered the need for enhanced sustainability and lean performance. This can be supported by BIM implementation as utilization of information and communications technologies (ICT) can contribute to the productivity [19]. This chapter focuses on BIM as a tool for enhancing sustainability and lean performance of the construction project management; as well as on the usage of BIM based on construction project management phases.

BIM AS A TOOL FOR ENHANCING SUSTAINABILITY AND LEAN PERFORMANCE OF THE CONSTRUCTION PROJECT MANAGEMENT

BIM and Sustainability Performance

The construction industry has an environmental footprint due to its production/construction process as well as due to its outputs. The construction industry has been identified to be responsible for: more than 30% of the global energy consumption; 20% of freshwater withdrawals worldwide, and 33% of global greenhouse gas emissions [20] as well as for raw material consumption. The output of the construction industry is a built environment which has significant environmental, economic, and social impacts [21] ("*e.g.* the built environment is the largest consumer of energy and greatest contributor to climate

CHAPTER 9

BIM-Integrated Life Cycle Assessment in Environmental Analysis – Current Status and Future Development

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Abstract: Due to the rising recognition of environmental sustainability, environmental assessment has been a core task for construction projects. Traditional environmental assessment of construction projects follows the Life Cycle Assessment (LCA) rule and principles, which may be time consuming and require extensive manual inputs. In recent years, many studies has been initiated to use Building Information Modelling (BIM) as the platform to host LCA implementations. Benefits, including increased productivity and flexibility, have been recorded. However, some problems, such as varied scope and definition, have also been identified. It is therefore necessary for the construction industry to understand the current status and future development of BIM-integrated LCA. A systematic review shows that BIM have been used as the platform to host LCA implementations for various project life cycles (including production, transportation, construction, operation and end-of-life stages) and environmental impacts (mainly including energy, carbon emissions, water and waste). In addition, future actions are needed in the aspect of standardization, benchmarking and available of databases in order to allow accurate comparison of the environmental performance between different projects and design alternatives.

Keywords: BIM-integrated LCA, Building information modelling, Environmental sustainability, Life cycle assessment.

INTRODUCTION

Human development has put on significant stress on the environment. Some typical environmental impacts include depleting natural resources, rising sea levels and global warming. For example, the global sea level has been rising at a rate of 3.1 mm/year since 1993 [1]. Greenhouse gas emissions are recognized as

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one of the most significant contributors to global climate change [2].

The building and construction industry is considered as one of the most significant sources of greenhouse gas emissions. For example, the cement sector is estimated to generate 5% of global carbon emissions [3]. In addition, the manufacturing process of raw materials (*e.g.* cement and steel) also generate a significant amount of carbon emissions [4, 8, 9]. Along with the manufacturing industry, transportation is also considered to be one of the largest sources of carbon emissions [5]. Additionally, the construction industry is not considered as an efficient industry, which can generate unnecessary emissions [6]. Due to its significance, the construction industry is facing increasing pressure on environmental management, such as solid waste management [7]. Construction and demolition waste is one of the largest sources of solid waste [10]. According to [11], 25% of the solid waste generated from the European Union is categorized as construction and demolition waste.

The rising recognition of environmental sustainability and global warming may affect the construction industry at different levels. Governments may impose limits on waste and emissions for construction activities, including manufacturing, procurement and construction activities, in the near future. In addition, with the global recognition of "green" certification, construction companies need to take environmental performance into consideration in order to survive in the global competitive construction market. In some cases, construction products/projects have to obtain some level of green certifications before they can be approved or implemented. As many government incentives are now available for green projects, investing in environmental performance will not only improve the public perception of the company, but also bring about considerable benefits.

For example, one central issue for the effective management of carbon emissions in the construction industry is to accurately assess the carbon emissions levels of construction projects. According to [7], the assessment of carbon emissions level is built on life cycle assessment (LCA) guidelines, including ISO 14040:2006 [12] and ISO 14044:2006 [13]. The LCA concept is defined as compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [12]. The assessment is preferred to be completed at the early stage of the construction project so that alternative designs can be compared. However, as the LCA method requires the inputs and outputs of a complete life cycle, many studies have found that the application of LCA in the construction sector is very scarce [14].

Building Information Modelling (BIM) is a digital representation of the project's physical and functional characters, which is based on the three dimensions technology and integrates the necessary information required by the Architecture, Engineering, Construction and Facilities Management (AEC/FM) [15]. BIM has proven to be effective on information delivery and can be used as the platform to host life cycle assessment. For example [16], argued that automatic inventory analysis and environmental impact assessment can be conducted using BIM to facilitate building design and decision makings in various aspects. However, as the use of BIM to host LCA is still in its infancy, it is necessary to understand its current development, from which useful experience can be drawn. This book chapter therefore aims to: (1) examine the theoretical support of the integration of LCA and BIM; (2) investigate the current development of the integration of LCA and BIM; and (3) point out the future directions of the integration of LCA and BIM.

LIFE CYCLE ASSESSMENT

Step 1: Goal and Scope Definition

Life cycle assessment (LCA) is commonly used as an evaluation method of environmental impacts [17]. Based on the life cycle assessment methodology, elementary flows and potential environmental impact to a specific product system will be assigned. A typical LCA study should follow a four-step procedure, which is shown in Fig. (**1**). As can be seen from Fig. (**1**), a life cycle goal and scope definition should be determined before the commencement of the life cycle analysis. According to [12], the goal and scope definition of an LCA provides a description of the product system in terms of the system boundaries and a functional unit. The system boundaries define the life cycle stages that will be included in the life cycle study while the functional unit is the unit of measurement which can be the quantity of the product or other alternative unit of measurements on the basis of per cubic metres or per square metres.

According to [12], although cradle-to-grave is preferred, due to the long period of operational stage, many studies use cradle-to-gate as the system boundary. The reasons leading to such practice are twofold. First of all, the operational and the end-of-life stages usually include a very long time span that includes many uncertainties. As such, it will be difficult to ensure that all uncertainties can be objectively measured. In addition, many studies argued that the impact of operational and end-of-life stages is minimal and therefore can be excluded from the LCA study [18].

In addition, as there are various environmental impacts in the life cycle of a product or product system, it is necessary to identify the environmental impacts that will be covered in the LCA study. For example, the LCA method can be used to calculate the impact of the product or the product system on global climate

CHAPTER 10

The Impact of Building Information Modelling on Quantity Surveying Practice and Project Performance

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Abstract: The construction industry globally is known to be very conservative in terms of the methods used in project procurement and delivery. Scholars and construction professionals consider the use of innovative software such as Building Information Modelling (BIM) will result in a change in the roles and responsibilities of quantity surveyors and in improved project performance. However, there is a dearth of literature that demonstrates the impact of BIM on quantity surveyor roles and responsibilities, and project performance. This chapter examines the use of BIM in the construction industry and whether it impacts on the key roles and responsibilities of the quantity surveying professional and on construction project cost performance in South Africa. The study on which this chapter is based proposes that BIM has no impact on the conventional roles and responsibilities of quantity surveyors and project cost performance and adopts a sequential mixed-methods research approach which involves collecting and analysing quantitative and qualitative data in two successive phases within one study. The population of the study comprises of quantity surveyors in the South African construction industry. The results indicate that BIM has a negative impact on project cost performance and that the traditional roles and responsibilities of quantity surveying professionals in South Africa have not changed owing to the implementation of BIM technology, although BIM has improved the efficiency with which quantity surveyors perform their tasks. Based on these findings, the study concludes that the implementation of BIM technology on construction projects in South Africa will not change the responsibilities and roles of quantity surveyors on projects. It is therefore recommended that South African quantity surveyors use BIM technology on projects to realise the full benefits derived from its implementation internationally. However, further research is required to investigate other aspects of the implementation of BIM in the construction industry by using a larger sample and project size.

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Keywords: Building Information Modelling (BIM), Construction industry, Cost performance, Quantity surveyor, South Africa.

INTRODUCTION

Building Information Modelling (BIM) is a multi-faceted tool that offers a smooth integration of information from various types of software into one format [1]. Despite often being considered a three-dimensional (3D) modelling function used by designers, BIM software is capable of linking the modelling function to data concerning time schedules and planning of the progressive phases of the project; it also has the ability to develop material take-offs and cost estimates [2]. There is an evident overlap in the capabilities of BIM software and the work traditionally done by the quantity surveyor. According to Gee [3], the responsibilities of a quantity surveyor involve the management of the costs of a construction project, from inception through to the final account, as well as the administration of the contract between the client and contracting parties.

BIM is a technology that enables the achievement of enhanced profitability, reduced costs and more effective time management on building projects [4]. According to [5], BIM is currently implemented to varying extents in the construction industry internationally and the various role players on construction projects are affected by its use, with quantity surveyors being no exception. As noted by [5], the adoption of BIM may lead to the traditional roles of construction professionals, including quantity surveyors, being redefined. In addition, Gee [3] posits that the potential capability of BIM to automate the production of bills of quantities could in itself represent a major shift in the fundamental responsibilities of the quantity surveyor.

It is however not known whether the use of BIM technology on construction projects has translated into a major shift in the fundamental responsibilities of the quantity-surveying professional, nor is it known whether the implementation of BIM has resulted in improved project performance. This chapter presents a study that addresses these lacunae by examining the extent of use of BIM technology by quantity-surveying firms in South Africa and the roles and responsibilities of quantity-surveying professionals on construction projects. It also examines whether the implementation of BIM technology on construction projects impacts on cost performance. The chapter further reviews pertinent literature on BIM technology, quantity-surveying responsibilities, and project performance. The research methodology used in the study is outlined and findings froma questionnaire survey and personal interviews are presented. From these findings, conclusions are extrapolated, followed by recommendations.

OVERVIEW OF BIM TECHNOLOGY

In this section, the use of BIM technology, including software types, the impact of BIM technology on the traditional roles and responsibilities of the quantity surveyor and the potential impact of BIM on construction project performance is reviewed.

Use of BIM Software in the Construction Industry

BIM consists of five dimensions – the 3D component involves design, while the 4D and 5D components refer to time-related and cost-related aspects respectively which are linked to the design drawing [6]. BIM enables the integration of information from different sources, rather than being one tool that incorporates all those capabilities [1]. This integration can incorporate a 3D model with semi-structured and unstructured data files, unstructured graphic files, and unstructured multimedia files [7]. According to Boon [6], while the 3D component of BIM – often referred to as the 'platform' software – may be prospering, the 4D and 5D software used in conjunction with it has not experienced the same effect. The quantity surveyor, as the professional cost consultant of the design team, would naturally be more focused on the 5D component of BIM – Exactal's CostX® is one such example of where a 5D software component can easily be linked with a 3D component such as Autodesk Revit®.

A survey completed in 2013 by the National Building Specification (NBS) to gauge the construction industry's perception and understanding of BIM technology found that both users and non-users generally agreed that BIM improves visualisation of the details of the project. BIM users were slightly more positive towards some of its features than non-users, while more users agreed that BIM improves productivity owing to easy information retrieval information and cost efficiency [8]. A survey by the Royal Institution of Chartered Surveyors (RICS) [9] worldwide found that BIM's use was limited; however some use and awareness of BIM suggest that it is a burgeoning concept in the profession.

Factors Influencing the use of BIM in the Construction Industry

Several factors have been documented in literature as influencing the use of BIM in the construction industry. Project performance benefits in particular have been emphasised – BIM has the ability to facilitate greater interoperability between project stakeholders (clients, professional team and the contractors) because the construction industry is 'highly collaborative', particularly within the project design and execution phases [3]. In addition, it enables project businesses to become more efficient as it speeds up the process of design, costing and construction by means of automation, visualisation and better co-ordination of

CHAPTER 11

Development of BIM Courses in Civil Engineering

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Abstract: Considering the huge potential of Building Information Modeling (BIM) for use in construction projects, modern Architecture, Engineering, Construction and Operation (AECO) industries are increasingly recruiting graduate engineers with BIM knowledge and skills. Globally, university AECO departments are investing time and resources in designing BIM courses for faculty and students at different levels. This article provides an overview of the current BIM courses taught in-class and online by Department of Civil Engineering at National Taiwan University (hereinafter referred to as 'NTUCE'). Detailed discussions are given on a basic in-class BIM course taught at NTUCE, titled "Technology and Application of BIM", and its curriculum with focus on course objectives, course description, teaching resources used for the course, course contents, teaching methodologies, course discussions, and the evaluation process involved. Also, we provide an overview of the three online BIM courses developed by NTUCE on the Coursera platform of xMOOCs model, *i.e.,* Engineering information management: BIM Concepts, BIM Modeling and BIM Applications and CAD/BIM practical capstone project.

Keywords: BIM Education, BIM Curriculum, Civil Engineering program, In-class BIM courses, Online BIM courses.

INTRODUCTION

As a technology and project process, BIM has become popular over the past decade. Research conducted at the Civil Engineering department of National Taiwan University (herein after "NTUCE") shows that AECO industries in more than sixty countries are delivering projects with BIM technology, highlighting the potential benefits of BIM for construction projects. These recent trends of BIM practice in AECO projects has resulted in the increased hiring of graduates exposed to BIM tools, concepts and related processes. Accordingly, many universities around the world are introducing a wide range of BIM courses to expose AECO students to BIM. A recent literature review conducted at NTUCE

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revealed that BIM education is provided in several universities at different tertiary education levels for departments associated with AECO to produce “BIM-ready graduates” and “BIM specialists”.

Global Trends in BIM Education

A research study on global trends in BIM education was conducted at NTUCE [1]. This included review and analysis of “BIM Education” and its associated publications (*i.e.* journal publications, conference papers, research theses, and reports) from 2010 to 2015 from more than twenty countries, including Canada, USA, Brazil, UK, Ireland, Denmark, Belgium, Turkey, Latvia, Egypt, UAE, Israel, Nigeria, Indonesia, Singapore, Malaysia, India, China, Hong Kong (China), Taiwan, Korea and Australia by adopting textual and content analysis techniques. This resulted in a BIM education related collective knowledge base which can assist BIM policy field players (for instance, BIM educationists and researchers) in integrating BIM into AECO departmental course curricula. In addition, the outcome of this study helped to develop an understanding of the efforts of globally active BIM policy field players in the field of BIM education research:

Need for BIM Tertiary Educational Institutes (TEIs)

Efforts were undertaken by active BIM educationalists to incorporate BIM into curricula of AECO-associated departments, thereby facilitating AECO industry needs [2 - 4].

BIM Educational Framework Development

Several BIM educationists have conducted extensive research in developing a BIM educational framework for different tertiary education levels and its application [5 - 8] to several AECO-industry associated departments such as Civil Engineering, Construction Engineering and Management and Quantity Surveying [9 - 12].

BIM Related Curricula Development

Our study reveals that BIM educationalists design courses by taking into account factors such as course contents, prerequisites, course objectives, teaching methodology and the evaluation process for planning and developing BIM related curriculum to several AECO industry associated departments, *i.e.*, Architecture [13], Construction Management [14] and multidisciplinary subjects [15 - 17] with several tools [18] and techniques [19 - 21].

Assisting AECO Industry Specialists on Essential BIM Skillsets

BIM educationists educate students to acquire BIM knowledge and skills (technical, operational, functional, implementation, administration, supportive, managerial and R&D) based on the prerequisites of several BIM specialists (BIM modelers, BIM analysts, BIM application/software developer, BIM manager or coordinator, BIM consultant and BIM researchers) by adopting several training techniques [22 - 25].

Testing BIM Courses within AECO Departments Curricula of TEIs

BIM course introduction, experimentation, and evaluation have been undertaken by many active educationists and researchers from the USA, the UK, Belgium, Latvia, China, Taiwan, Indonesia, Thailand, and Malaysia in several departments [1], such as Civil Engineering [26 - 29], Architecture [30 - 34], Construction Management [35, 36], Facility Management [37], Quantity surveying [38], and several other multidisciplinary departments [39 - 41]. Several BIM courses were taught in conjunction with thematic concepts, such as sustainability with green concepts [42], project execution planning processes [43], and laser scanning technology for rehabilitation [44]. Techniques used in conducting BIM courses include professor-student collaboration [45], project based learning, team process [46], industry academia alliance [47], and career orientation [48].

Developing Strategies to Overcome BIM Educational Issues

Several globally active policy field players integrated BIM into academia and experienced several complications. These complications were categorized into technology, policy, and process-related issues. Further, strategies to overcome the issues were discussed [49 - 51].

BIM policy field players, especially BIM educationists, educational institutes, research centers and regulatory bodies are integrating BIM into tertiary education systems by diffusing BIM into the curricula and core courses of AECO departments. Fig. (**1**) shows BIM education publications (*i.e.*, research theses, reports, journal articles, and conference papers) trends and clearly indicates that policy field players are recently showing more interest than before in integrating BIM into the curricula of AECO departments.

In the past, BIM researchers attempted to emphasize the evolution of BIM in education, especially regarding current approaches of BIM teaching strategies and the BIM learning spectrum, and to give an overview of the main obstacles encountered with BIM teaching at universities around the world [20, 52, 53]. Also, literature review conducted at NTUCE revealed that a few globally active

CHAPTER 12

Applications of Hazardous Gas Monitoring Integrated WSN and BIM Technologies in Underground Construction Sites

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Abstract: In recent years, several research efforts have focused on the application of information technology (IT) as a means by which to improve the integration process of construction safety management. Visual representation can provide an effective tool for monitoring and management in the field of safety management. In Taiwan, monitoring of hazardous gas detection on the underground construction sites is a very important issue. In order to enhance the performance of controlling in hazardous gas detection in underground construction sites, this chapter proposes a solution for the integration of building information modeling (BIM) and wireless sensor networks (WSN) technologies to enable the monitoring of hazardous gas conditions in underground construction site and provides warning signals. WSN consist of small nodes with sensing, computation, and wireless communication capabilities. First, the proposed methodology is implemented by using BIM technology due to its capability to accurately provide visual safety-related status indications with different colors. Furthermore, in order to support the wide range of safety analysis used wireless communication capabilities, proposed BIM-based safety monitor system is developed. Thus, this chapter examines the use of the BIM-based safety monitor system to provide the flow of safety information collected by WSN sensors, and visually illustrates the status of detection and alarm regarding to hazardous gas with different colors. A case study is presented to demonstrate the applicability of the proposed approach. Finally, benefits, limitations, conclusions, and suggestions are summarized for further applications.

Keywords: BIM, Construction jobsite management, Hazardous gas, Safety management, WSN, ZigBee.

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INTRODUCTION

The international statistics for occupational safety indicate that the construction industry has one of the highest accident rates [1], many construction fatalities and injuries were caused by unsafe environment and poor safety management, implementations of modern information and communication technologies can provide great potential enhancements in construction safety management [2]. According to the occupational accidents survey [3], hazardous gases and lack of oxygen were the main causes of injury in confined space operations. Many underground construction sites contain confined spaces, not only the working conditions are poor, but the workers inside are potentially exposed to harmful gases. Confined spaces have been defined by the American Occupational Safety and Health Administration (OSHA) as "spaces are not designed for continuous occupancy and are difficult to exit in the event of an emergency" will be treated as a confined space [4], people working in confined spaces may possibly face life-threatening hazards problems (such as toxic substances, electrocutions, explosions, and asphyxiation). According to the investigation of National Census of Fatal Occupational Injuries conducted by the U.S. Bureau of Labor Statistics (BLS) in 2014, there were approximately 4679 fatal occupational injuries in America. Of these fatal injuries, 8% were caused by exposure to hazardous environmental conditions and 3% were caused by fire and explosions [3]. The statistical data indicates that more effective methods and technologies for monitoring and reducing the disaster potential can improve worker safety. Injuries associated with confined space entry include personnel hypoxia, poisoning (by substances such as hydrogen sulfide and carbon monoxide) and fires and explosions caused by a build-up of flammable gases (such as methane and ethane). In the construction industry, some examples of typical instances of injury include hypoxia – or fire/explosion – caused by the occurrence of high concentrations of methane underground; poisoning caused by harmful gases from welding, cutting, and paint solvents; and engulfment or explosion caused by accidental leakage occurring in oil or gas pipeline excavation. In particular, some flammable gases such as alkanes and carbon monoxide are usually colorless and odorless, and thus are not easily detected by humans. Because of their difficulty in detection, such gases can easily lead to casualties.

To reduce the accident rate caused by hazardous gases, worldwide government departments responsible for health and safety management are all engaged in the minimization of the risks caused by gas hazards and the drafting of the relevant laws and regulations. For example, employers have the duty to ensure worker safety and recognize hazards when laborers are working in confined spaces, and must also provide equipment to measure oxygen concentration and detect hazardous substances in order to avoid the occurrence of occupational accidents.

Building information modeling (BIM) was rapidly developed and widely applied in the Architectural, Engineering, and Construction (AEC) industry in recent years [5]. There are also many popular BIM applications are popular in the AEC industry such as Revit, Tekla Structures and Bentley AECOsim [6 - 8]. BIM provides an effective visual platform for use in design and construction activities and facility management. Moreover, as wireless and micro-electromechanical technology has increased progressively, the application of wireless sensor network (WSN) and Internet of Things (IOTs) has been extensively promoted and become an area of particular interest. WSN is a network consisting of several sensor nodes that can collect, store, and process environmental information and communicate with other nodes and return data [9]. The BIM provides an visual platform for data integration and demonstration, which also provides a novel applicable solution in safety management.

In order to improve the hazardous gas monitoring in underground construction site, this chapter presents a BIM-based safety monitor system integrated with ZigBee wireless sensor network technology to enhance the monitoring of hazardous gas detection. The system was implemented in an underground construction site to monitor levels of hazardous and flammable gases such as methane, propane gases and other hazardous substances, for the purpose of effectively monitoring hazards and thereby reducing risk of worker injury. The purpose of this study includes:

1. To propose the application framework of hazardous gas monitoring by integrating WSN and BIM technology in the underground construction site.
2. To developing BIM-WSN based combustible gas monitoring modules and systems.
3. To identify the benefit and the limitation regarding to the developed system.

BACKGROUND

Building Information Modeling

Building Information Modeling (BIM) is defined as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle." by National Building Information Model Standard Project Committee (NBIMS-US) [10] which has been rapidly developed and widely applied in the construction industry in recent years [11]. BIM enables various information to be incorporated into a 3D visual model such as spatial configurations, dimensions, materials, layout of equipment and pipelines [12], this approach provides plenty of applications in all stages of the building life cycle

CHAPTER 13

The Future of BIM Technologies in Africa: Prospects and Challenges

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Abstract: The construction industry is undergoing a radical change as project owners are demanding for more project visibility at lower cost and better risk management; this has increased the use of new technologies in project implementations. The concept of information islands has remained a major challenge in construction projects where the existing management systems have restrained the sharing of information on the building life cycle and also cooperation among contracting parties. The global call for the use of building information modeling (BIM) is to improve the quality characteristics of the construction industry's outputs and create potential impact on the industry. The upgrading from the use of 2D CAD systems to 3D BIM technologies has dramatically increased project efficiency and affordability among the large architecture, engineering and construction (AEC) firms. The chapter investigates on the prospects and possible challenges confronting the upgrade to BIM technologies in the two leading African economies namely; Nigeria and South Africa. The research approach is based on comprehensive literature scan and case studies. The findings reveal the key challenges to adopting BIM in both countries, the paper also recommends the way forward.

Keywords: BIM technologies, Construction industry, Nigeria, South Africa, 2D.

INTRODUCTION

The global construction industry is on the verge of significant shift in the ways projects are delivered by focusing not only on tradition design but environmental, economic and social effects of a building project as a whole. This has risen the demand for sustainable buildings delivered through sustainable design and construction practices anchored on such factors as climate, culture, place, building type and resource consumption [1]. Plausibly, building information modelling (BIM) and sustainability are two important primary trends driving these changes

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in the industry. Proponents of BIM such as [2 - 4] hinge its growing popularity on the ability to achieve effective communication and collaboration between project stakeholders as well as improvement of project outcomes over the entire building life cycle (design, construction, and facilities management). BIM is a generic term used to describe the process of digitally generating, representing and managing buildings and information related to them using advanced 3D Computer Aided Design (CAD). These information include geometry, space relationships, geo-graphic information, quantities and properties of building components. It is a technology that transited from the traditional 2D paper based drawings fraught with errors and waste as well as poor coordination to 3D digital models on computer screen. In a report commissioned by SMART Market and published by McGraw-Hill in 2008, two-thirds of BIM users were said to be experiencing positive return on investment (ROI) in their overall investment in BIM; 87% of expert users were experiencing positive ROI with BIM; while 93% of BIM users believed that there is potential to gain more value from BIM in the future.

It is therefore no surprise that several developed countries of Europe, America and Asia have all adopted BIM for design, construction and building aftercare (facilities management) by architecture, engineering and construction (AEC) firms. Many of such developed countries including United States, United Kingdom, Australia, Denmark, Norway, Japan, and Hong Kong are reported to have embraced this novel technology in virtually all sectors of their construction economy and have recorded substantial growth and improved project delivery. As with other developed and developing nations, construction is vital to Nigeria's economic development which is why it produces nearly 70% of the nation's fixed capital formation and accounts for 1.4% of the country's GDP [5]. Nigeria is the most populous nation in Africa, with a young population of 140 million by the 2006 population census [5] and presently an estimated 160 million based on 2006 projection of 2.3% annual growth rate. The country's economy had a GDP growth of 7.37% in the third quarter of 2012 and in 2014, its GDP growth was 6.3% [5], while its GDP is now the largest in sub- Saharan Africa (ahead of South Africa). Despite these, the Nigerian construction industry is yet to fully embrace the BIM technology owing to several constraints and challenges bedevilling the sector.

South Africa has a population of about 51.6 million with 60 percentage of the population below 35 years [6]. The country has the second largest economy in Africa with a world class infrastructure which includes widely available energy, modern transport network and hi-tech telecommunications. The country's economy has recorded an average GDP growth of 2% from 2008 to 2012 and in 2014, its GDP growth was 1.5% [7]. BIM usage has received a great welcome and excitement among the structural and civil engineering sector. BIM implementation is limited to 3D modeling and interface management, the spectrum of BIM has yet to be fully utilised in the industry. Giving the background above, this paper aims to investigate these challenges as well as highlight promising prospects of the adopting BIM technologies in Nigeria and South Africa using a review of extant literature and case studies.

CHALLENGES OF BIM TECHNOLOGIES ADOPTION IN DEVELOPED AND DEVELOPING COUNTRIES

Literature review highlighted several limitations to the adoption of BIM technologies in the construction industry both in developed and developing countries. The Royal Institute of Chartered Surveyors [8] confirmed that lack of awareness among stakeholders, lack of standard to guide implementation, lack of information technology (IT) infrastructure, lack of education and training, lack of government direction as major challenges faced in the adoption of BIM technologies. Other factors adjudged as general challenges faced by BIM stakeholders in its full adoption include lack of knowledgeable and experienced partners, legal and contractual constraints, lack of industry standards, and high cost of implementation. However, argued that lack of highly skilled staff [9], unfamiliarity of firms with the use of BIM, reluctance to train staff or initiate new work orders, lack of proof for tangible benefits of using BIM, cost of training and high cost of BIM software. In yet another study [2], posit that the challenges include process barriers including legal and organisational challenges and technology related barriers. In the same vein [10], had earlier classified these challenges as problems arising from computability of digital design information, meaningful data interoperability, and transactional business process evolution.

In Nigeria [11], revealed the challenges confronting the BIM usage as (1) the scale at which a fully loaded central BIM project database can be managed. This is because BIM systems are naturally designed to create very large and complex files; (2) multi-disciplinary design teams find it difficult to adopt single BIM interface such as object versioning, object-level locking, and real-time multi-user access; and (3) there is contradiction in work processes when using a single detailed BIM to try to represent a number of alternate design schemes. However [12], recently in an empirical study identified poor internet connectivity, frequent and epileptic power infrastructure, lack of awareness among stakeholders, legal and contractual constraints, social and habitual resistance to change, lack of enabling environment, and high cost of integrated models as problems confronting successful adoption of BIM devices in Nigeria. The recent case study reported by [13] on BIM usage in Nigeria, highlighted two major benefits which are proper clash management and effective communication. The study demonstrated that BIM is still in its infancy within the industry and the spectrum of BIM usage has not fully utilised.

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