Publication 395

The Economics of BIM and added Value of BIM to the Construction Sector and Society

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The Economics of BIM and Added Value of BIM to the Construction Sector and Society

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CIB Student Chapter

- Sebestyén Future Leaders Award 2012 -

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Foreword

Purpose of the CIB's Sebestyén Future Leaders Award is to expose future leaders of the building sector to the latest developments in building research. CIB Student Chapters are encouraged to team up with CIB Working Commission(s) to develop the research idea and proposal for the Award submission.

The CIB Student Chapter of The University of Salford in the United Kingdom was the Award Winner for the Sebestyén Future Leaders Award in 2012. The University of Salford's Student Chapter had developed a collaborative research together with the CIB Working Commission 55 – Construction Industry Economics, and the title of this project is: "The Economics of BIM and Added Value of BIM to the Construction Sector and Society". The project was successfully completed in summer 2013. Congratulations to The University of Salford's Student Chapter for the achievement.

I take this opportunity to introduce to you the research report and wish that you enjoy reading it.

Prof. Francis Wong

Chairman, CIB Student Chapters Committee

and Member, CIB Board

12 September 2013

Executive Summary

Since the publication of Sir John Egan's report on the state of the UK construction industry 15 years ago (Egan, 1998), there have been remarkable improvements. The UK's newest 2012 HM Government Report challenges the industry to step forward and embrace technological change. Though, as with every industry, sector, or organisation, the need for continuous and sustainable improvement continues to push the boundaries and is slow in acceptance. The construction industry is no exception to this phenomenon. As cost is a major factor in any construction project, there is an ever growing need to keep it at manageable levels, while still seeking to achieve the desired budget, quality and delivering on time.

Innovation in information, communication, technology and process management has contributed to making this achievable. The industry has witnessed a radical change in the form of Building Information Modelling (BIM). This has revolutionised the delivery approach to construction projects. Evidence of a quantum leap into the realm of BIM has been reported in various forms such as journal articles, industry reports, magazines and case studies. New project delivery processes and approaches to delivering construction projects, such as Integrated Project Delivery (IPD), have been developed as well as Lean Construction, which have been pioneered in the USA and the UK. Better efficiency and collaboration between project stakeholders on a global scale have been engendered on complex projects in France, China the UK and USA.

Overall, BIM has witnessed positive adoption in China, the USA, Europe and Australia. This tends to portray an overwhelming support and benefit of BIM in the construction industry. On the other hand, little has been done to determine the economics and the added value of BIM to the construction sector and society holistically. This presents a major challenge for investors in determining what the real value of adopting this approach to current and future projects will be. If BIM is to take-off and adopted holistically by all stakeholders in the AEC industry, then a better understanding of its economic value must be rectified. Currently, there is no standardised methodology or approach in determining its economic value, which has been highlighted in this report. Current efforts have been made by way of investment appraisals such as Net Present Value (NPV), Discounted Cash Flow (DCF), and Cost Benefit Analysis (CBA), yet this has been engaged at the micro-level of organizations. Hence, its application at a macro global level is not robust enough as other factors that affect world economies are not considered.

This report draws attention to the above issues and proffers an approach to overcoming this challenge. Within the report, benefits of BIM have been highlighted. Moreover the challenges experienced by industry experts have been elucidated. Finally an approach to determining the economic benefit of BIM has been offered. This uses the economic concept of Total Factor Productivity (TFP). Consequently, in order for BIM to be successful there has to be a paradigm shift from traditional silo disciplines of architecture, engineering and construction to a more collaborative management practice, which stipulates a process management, operations management and lean management approach that will create an overall workforce with enhanced skills, supported by information and knowledge technologies.

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Abbreviations

A-BIM	Architectural/Design BIM model, the original model produced by the architectural firm
AEC or A/E/C	Architecture, Engineering and Construction Industry
AECOO	Architecture, Engineering, Construction, Operations and Owner Industry
AE	Architecture Engineering Firms and /or Industry
AIA	American Institute of Architects
BIM	Building Information Modelling
bSa	buildingSMART alliance™
C-BIM	Construction BIM model, the model that is produced by the construction firm solely for construction. It will have 4-D (scheduling) and 5-D (estimating) software components attached for 'real-time' construction scheduling, estimating and phasing
DOE	U.S. Department of Energy
F-BIM	Fabrication BIM Model, the model used for fabrication of construction systems
GenY	Generation Y
GSA	General Services Administration
ICT	Information and Communication Technology
IFC	Industry Foundation Classes
MHC	McGraw-Hill Construction
VD or VDC	Virtual Design or Virtual Design and Construction

1 Introduction

The overall focus of this report is to provide the CIB (International Council for Research and Innovation in Building and Construction) Board members with a comprehensive overview of the proposed 2012 CIB Sebestyén Future Leaders Award report, to include research aims, objectives, philosophy and contribution to the body of knowledge. The University of Salford's CIB Student Chapter research team has worked under the guidance of the Joint Coordinator for CIB W055 Construction Industry Economics to prepare this report.

1.1 Background to the Report

According to Eastman *et al* (2005), Building Information Modelling (BIM) "is one of the most promising (technological) developments in the architecture, engineering and construction (AEC) industry". Although it is not technically a new concept, BIM is changing the ways in which project stakeholders are working by affecting the way that buildings are designed, constructed, and operated. Forbes *et al* (2011), define BIM as: "… the process of generating and managing building data during its life cycle". Additionally, BIM is considered a process and tool that is known to "increase productivity and accuracy" (Forbes *et al*, 2011) in the design, construction and post occupancy phases of facilities. Whether it is a transportation project; building; educational; infrastructure project; environmental project to include water and wastewater; pharmaceutical, nuclear, manufacturing; and operations and maintenance, BIM integrates three-dimensional design aspects with construction attributes in a current 'real time' state.

Technology becomes the dominant factor in the success or demise of construction projects and of architectural/engineering (AE) construction firms. Kapogiannis *et al* (2010) argues that integrated design as a concept using BIM and other similar technologies to operate efficiently impacts team collaboration. Integration throughout the design and construction phases supported by BIM fosters team collaboration, which leads to a positive major impact on project performance. Literature suggests that it is the "I" in BIM that creates the integration between the computer models, software interoperability, project requirements and specifications, stakeholders and the overall project success.

Therefore, we envisage that there is a vast need to research the economic impact of BIM on the global built environment. The output of this contribution is to support the local and international AEC community. Hence, the impact of this research activity both supports the economics and social vision of BIM and its current value to the AEC community and society and the requirements of the CIB 2012 Sebestyén Future Leaders Award.

1.2 Context of the Research and BIM's Potential

The term "ICT" encompasses the accessibility, integration, communication, and sharing of computer software, hardware and additional IT devices and their information on a local and worldwide level (Forbes *et al*, 2011). As the internet expands and the need to communicate, collaborate and share project information becomes more of a global activity, ICT becomes more important, it becomes an everyday tool. Globalization has become the norm, there are no borders and the workplace of today is rapidly changing. In order to remain competitive and one step ahead of the competition, AEC firms need to embrace these technologies more specifically, through sharing of useful information, communicating and collaborating data analysis, 3-D visualization and BIM (Forbes *et al*, 2011). BIM is an ICT tool that can assist with greater project efficiencies and precision throughout the design and construction process. Built environment organizations whether construction, engineering conglomerates or small and medium enterprises (SMEs) are changing the way they do business and will have to adjust their workplace in order to except this modernization of technologies.

The built environment workplace is changing rapidly and is commensurate with Generation Y (GenY) entering the workforce. To the GenY workforce digital technology is second nature. They are believed to be the most innovative technologically savvy generation at the "forefront of technological progress" (Puybaraud, 2012) thus far. According to Hahn and Puybaraud (2012) GenY makes up some 80 million people that were born between the 1980s and early 1990s. This has a significant impact on the architectural, engineering and construction workforce and society as a whole. It is envisioned that the growth of society will contribute greatly to a highly technological built environment and BIM is at the forefront of our industry's hi-tech trends.

When BIM was first developed it was described as 'CAD on steroids.' On the other hand, BIM is much more than 3D drafting. When practised correctly, BIM is meant to support collaboration across a facility's life cycle. According to Green (2012), BIM allows for the flow of data throughout the life cycle of a project. The design BIM has 3-D components. This becomes very useful in viewing the design in three dimensions. Every major building system can be visually verified for interferences (Forbes *et al,* 2011). The mechanical, electrical, structural and fire/health and safety engineers can visually see the spatial relationships amongst objects in 3-D and look for clashes of systems such as pipes intersecting steel beams and ductwork, walls, lighting and electrical system interference. By visualizing the design in 3-D, it provides a three-dimensional picture image of the design intent. This can save time and money as the clients quickly view what the proposed project will look like. Conversely, not all 3-D models are actual BIM models. The 3-D model represents a solid geometric illustration of design components and is only the very foundation, the building block of a BIM model and the design and construction project.

At this stage, the original BIM model is often handed over to the construction firm or the project team to create the model needed to construct the project. The model is integrated with scheduling software that supports the construction effort. The software vendors have labelled this the 4-D and 5-D model. Contractors can now manage the construction phases and project schedules through the projects lifecycle. The 4-D model can furthermore assist the contractor with steel fabrication, ordering of materials, and delivery of construction components and phasing sequences of the overall construction project. Additionally, estimating software can be integrated creating the 5-D model. Since the original design model is composed of actual features, these attributes can be extracted for direct quantities and cost purposes. If a design change takes place and the model is revised and updated, the quantity and estimate will update simultaneously. The 6-D model is referred to as the facilities management BIM. This 6-D model can be used for post occupancy, operations and maintenance issues, space planning, asset management and renovations and construction of the new or existing facilities.

Thus, the increasing implementation of BIM has produced several impacts in the way people interact within the different phases of a design and construction project. In addition, technologies are evolving faster than ever and built environment professionals are required to keep track of these constant changes in order to compete in the global marketplace. The aforementioned scenario is the context for investigating the economics and added value of BIM in a broad perspective.

1.3 Aim and Objectives

The aim of this research is to investigate the economic impact of BIM on project performance and its overall impact on adding value to the AEC community and society as a whole. The objectives are:

- To disseminate the impact of BIM on the construction sector and AEC community;
- To explore the global perspective of BIM;
- To investigate the economic impact of BIM, its technology adaption in different contexts, and its relation to the concept of Total Factor Productivity;
- To study the added value of BIM implementation in the main project phases, in the interfaces between Lean Production and BIM, in the complexity of infrastructure projects, and in the Return on Investment (ROI) for companies adopting BIM;
- To propose future directions for BIM research in economics and added value.

1.4 Research Approach

The research approach used in this study was supported by a thorough literature review and a survey conducted with BIM practitioners from different countries. Firstly, a set of meetings between the research team was conducted in order to define the aim and objectives of this research. Secondly, a brainstorming session was promoted in order to define the basis for a systematic literature review (i.e. keywords to be used, databases to be consulted, reports from industry to be analyzed). Thirdly, two main perspectives were defined for this report, specifically the economic impact of BIM and the added value of BIM. Both perspectives focused on the AEC community's viewpoints. Fourthly, a questionnaire was submitted to a set of built environment practitioners from various countries. Fifthly, a set of case studies was selected in order to illustrate current practical implications of BIM. From the literature review, outputs of the survey, and case studies, the research team deployed an in-depth analysis of all collected data and delivered a structured discussion about the economics of BIM, its added value, and future directions for research of this topic.

1.5 Contribution for Academics and Practitioners

This research delivers a contribution to the embodiment of knowledge by exploring the economic variables of utilizing BIM on design, construction and infrastructure projects, as well as its overall impact on the AEC community and society. The intended outcome is to provide the CIB international community with the most current and significant research data available. The economic value and benefits of BIM in the built environment is exploding with a wealth of project performance indicators, BIM guides and industry surveys. This research looks at the current trends, industry partner reports and the economic data on BIM and elucidates current conditions of its impact on the economy, the built environment and society as a whole. It is anticipated that the value and originality of this report will influence future CIB research initiatives.

According to Dinesen (2010), there is reluctance to adopting BIM by many AEC team players due to the lack of standards. Furthermore, the cost benefit analysis of a BIM strategy has not yet been achieved. Moreover, there has not been a consistent measureable rate of return for assessing the value and benefits for the client. Although Dinesen's research was written back in 2010, we have come a long way since then in measuring the benefits of BIM and the significant value and impact on the industry and clients overall, or have we?

1.6 Contents of the Report

This report is organized in five sections. Section Two provides an overall perspective of BIM application in different countries and contexts. Section Three discusses the economic impact of BIM and Section Four investigates the added value of BIM. Finally, Section Five delivers concluding remarks, a brief discussion and suggested direction for future research.

2 A Global Perspective of BIM

This is an immense period for BIM usage and data reports. As global economic uncertainty continues to progress, governments/owners and clients are seeking leaner, more efficient process and procedures for implementation during the design and construction phase of their projects. BIM is being employed across the globe on a variety of projects at varied levels of adoption from prime contracting firms and large consulting organisations to small A/E firms (Underwood and Isikdag, 2011). In 2012 alone there has been an abundance of data collected, surveys and major industry reports published around the world. BIM practices and standard research in the AEC industry are being developed and adopted in countries such as Australia, China, Finland, Germany, Netherlands, the United Kingdom and the United States. Section 2.1 shares a glimpse of BIM development in the UK, U.S. and China. Section 2.2 illustrates the complexity of three vastly dissimilar case studies that have all adopted BIM in various ways throughout the design and construction phases of the projects: a museum in France, medical centre in the U.S. and a 121 storey spiraling skyscraper in China.

2.1 UK, US and China Developments

Despite the initial inertia of adoption in the UK, BIM has started gaining traction as a result of its added value, benefits, and return on investment (ROI) indicators (Waterhouse and Philp, 2013). An industry survey carried out in 2012 revealed that the percentage of UK construction industry using BIM has increased to 39%, up from 13% in 2010. While the number of those who have not heard of BIM has been reduced from 43% to just 6% in the same period (Waterhouse and Philp, 2013). This represents positive evidence of growth across the UK which has been facilitated by central government policy and the requirements set forth by the Government Construction Strategy (HM Government, 2012; Lorimer and Bew, 2011). At present there is a real thirst for knowledge of how to plan not only for greater efficiency, but also for better scrutiny and improved collaborative processes. Currently, the British Government is developing an open BIM standard for all construction projects in the UK to adapt BIM as part of their project delivery method by 2016. As the widespread adoption of BIM has seen a positive change in the way we communicate and collaborate on construction projects, in turn this sharing culture enables a more informed and aligned overall process (Waterhouse and Philp, 2013) and successful construction project.

One requirement of the UK's BIM standard is the implementation of Construction Operations Building Information Exchange, also known as COBie. The Army Corps of Engineers Engineering Research and Development Center in the U.S. first developed COBie on a National Guard project. The U.S.'s *National BIM Standard-United States* NBIMS-US™ new Version 2, makes use of COBie's platform as well. COBie allows access to current data in 'real time' throughout the project life cycle. It illustrates the significance of the "I" in BIM (Green, 2012). Yet again, it is the "I" in BIM that is alleged to integrate the sharing of project information and the added value of team collaboration and communications.

China is currently developing a National BIM Standard. The U.S. building Smart Alliance (bSa) is consulting with them on shared knowledge and intellectual property right protection (Smith, 2012). China recognizes the economic return on investment and added value of using BIM project delivery systems on complex construction projects. According to Wang (2012), the design and construction of the Beijing Olympic facilities would have been unattainable without the use of 3D images. If it were not for BIM and 3-D software, the complexity of the design and structural elements would not have been possible. Not only does BIM contribute greatly to the overall success of the project team, BIM also aids the supply chain in designing, fabricating, and constructing a leaner, sustainable, efficient project. Furthermore, the Chinese Ministry of Housing and Rural Urban Development published a national BIM standard program in 2012. Research institutes, design firms, contractors, software developers and educational facilities across China are getting on the bandwagon. BIM is catching on and it won't be long before they are using BIM project delivery systems throughout China's AEC industry.

Recent industry report findings suggest that BIM usage in the U.S. AEC industry has grown to 71% BIM usage from only 28% in 2008. The construction industry is leading with a 75% adoption rate compared to the architecture industry at 70% usage. According to the report, there are a number of increased benefits of embracing BIMSee Table 1.

Table 1 - Technical and Organizational Benefits of BIM in USA

Technical Benefits	Organizational Benefits
Improved functionality and interoperability of software	Increased profitability
Reduced errors and omissions	Repeat business and business development
Less Rework	Offer new services
Better cycle times of workflow	Staff recruitment and retention
Reduced cost, schedule and claims	Fewer claims and litigation

As for the return on investment for AEC organizations using BIM, the industry report suggests that team collaboration is most important as BIM is adopted more on projects. In addition to the development of more BIM process, procedures, standards and contracts, model sharing and cloud computing will soon become the industry norm.

At the same time, the *National BIM Standard-United States*™ (NBIMS-US™), Version 2.0 is being rolled out. According to Green (2012), "NBIMS-US™, Version 2.0 is a good metric of where we realistically stand with BIM" in the U.S. It "documents the level of consistent interoperability" (Green, 2012) and illustrates how different software packages can interconnect and exchange data in the facilities management industry. In 2013, the National Institute of Building Sciences buildingSMART alliance™ is developing NBIMS-USTM, Version 3 BIM standard. According to Green (2012) "the AISC BIM Committee made a major decision in changing the way they do business, deciding to move from their very successful CIMSteel Integration Standards (CIS/2) the product model for exchanging data about structural steel project information to an Industry Foundation Classes (IFC) based approach to interoperability". The AISC BIM Committee is undertaking this research as they are convinced that BIM can only add value and quality standards to the prefabrication of steel. Furthermore, NIBS is concurrently developing a data dictionary for the U.S. construction industry that will assist in the way in which data exchange and BIM models are integrated. An example would be if the architect designs a block wall and labeled it 'concrete block wall'. The contractor opens the architectural model and starts to develop their own BIM construction model and searches for a 'CMU' wall. They would not be able to locate one, due to the fact that the original attribute in the model is designated as a ‘concrete block wall’, not a ‘CMU’ wall. It is for this reason that NIBS is developing a data dictionary. The U.S. AEC industry is contemplating some sort of consistency with data exchange and vocabulary as the realm of BIM unfolds rapidly.

Furthermore, the U.S. General Services Administration (GSA) is the largest real estate holder in the world. They manage all U.S. Federal Government buildings and facilities, globally. They have been developing their National 3D-4D-BIM Program since 2003. The program has measured an array of 3D-4D-BIM applications on numerous capital projects. As a result, all major government projects in the U.S. that receive any type of public funding as of 2007 and beyond are required to implement BIM project delivery systems. Moreover, GSA is promoting the deployment of 3D, 4D and 5D BIM models on all of their projects. They continue to research BIM technologies and their effect on a project’s lifecycle. Additionally GSA is researching project delivery methods in the areas of building circulation, security vulnerability, energy efficiency, sustainability, laser scanning, 4D phasing and spatial validation (GSA, 2007).

The AEC industry is changing rapidly with technology leading the transformation. As a result there will be higher levels of design and prefabrication standards, updated digital contracts that appropriate BIM ownership, use of cloud computing and model sharing issues. According to Charles Eastman (2012), the industry will additionally see more just in time deliveries of prefabricated systems and daily schedule updates. With the widespread use of BIM throughout the industry and government regulations and standards being put in place, their influence will result in more awareness, leaner processes, more collaborative process delivery systems and successful construction projects from country to country.

2.2 Case studies

BIM is enhancing efficiencies in design and construction, and is being widely specified by owners and or contractors on complex projects globally. The implementation of BIM is starting to become the norm in the AEC industry. Below is a brief illustration of a variety of complex projects where BIM has been adapted and explored.

2.2.1 Paris Museum

In Paris, the new, iconic Foundation Louis Vuitton Art Museum is being constructed. The museum has been designed by Frank Gehry, Gehry Partners. According to Witt (2012) (a Director of Research at Gehry Technologies), the museum is a high profile piece of art that encompasses the complexity of design and information technology. The intricate project is said to "push the limits of BIM technology and demonstrates how BIM, enabled by a cloud-based file management and project collaboration platform, can help large distributed teams work together". When completed the museum will be host to major exhibits, permanent art collections, as well as a host of unique retrospectives, lectures and recitals.

Figure 1 - Rendering of the Foundation Louis Vuitton Art Museum (Witt, 2012)

The exterior structure (see Figure 1) is extremely complex. It is described by Witt (2012), as a sailboat fluttering through the water as its glass sails catch the wind. The glass facade is made up of various sizes of curved-glass panels representing 'sails' that are combined with the use of fibrous concrete representing an 'iceberg' aesthetic exterior. The overall design and specified material usage is meant to complement the local environment. An overview of the BIM dynamics of the project according to Witt is as follows (2012):

- BIM project delivery system with cloud based collaboration platform;
- Over 400 BIM model users and 15+ design teams worldwide;
- Nearly 100 gigabytes of BIM-based model data;
- Over 100,000 version reiterations of the BIM model to date;
- 19,000 unique CNC moulded glass reinforced concrete panels;
- 3,500 unique CNC moulded curved glass panels.

The project team consists of approximately 10 companies located all over the globe. The project architects are located in Los Angeles, while the other half of the design team is housed in Paris. Additional team players are located in Germany, Italy and the U.K.. One of the primary project challenges is the unique facade structure (Figure 2) that lends itself to the dynamics of a proficient collaboration amongst the globally distributed project team (Witt, 2012). On site, in the construction trailer are the main project partners - executive architect, facade engineer, mechanical and structural engineers and Gehry Technologies (GT), who have developed and are managing the BIM project delivery process.

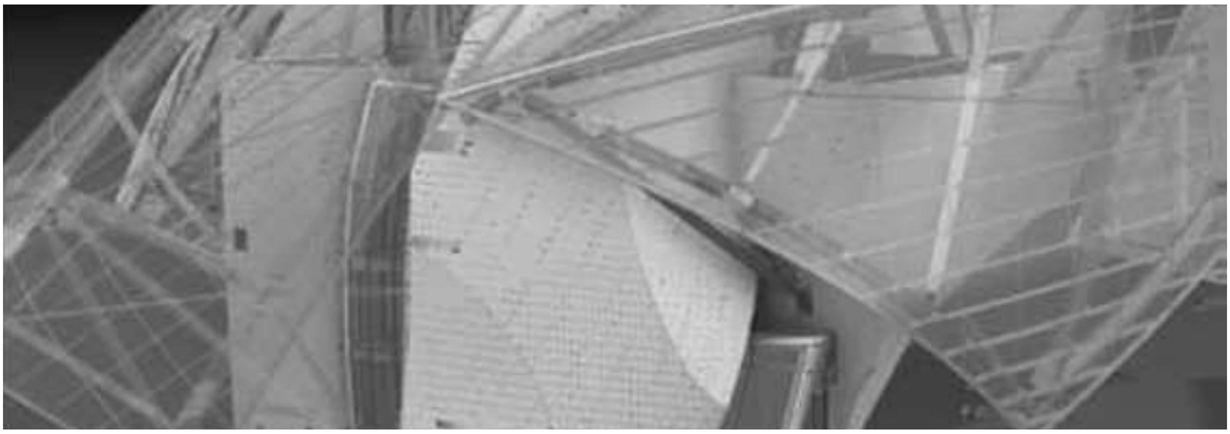

Figure 2 - Complex Exterior Glass Facade

The implementation and supervision of GT's BIM project delivery program has added tremendous value to the overall success of the project by keeping the cost, schedule and quality control on target. They have set up BIM project delivery system training modules for all parties involved with the project. The material fabricators have depended heavily upon the master BIM model. They are using it to extrude the necessary data needed in order to produce design intent shop drawings of the complex exterior glass components. Furthermore, every exterior glass 'sail' is being custom fabricated using the master building model (Witt, 2012).

The museum project is due to be complete in 2013. The American Institute of Architects (AIA) recently bestowed the project with the BIM Excellence Award.

"The project exemplifies how BIM can enable design, fabrication and construction excellence. The project draws from building expertise around the world. BIM software and cloud-based collaboration enabled concurrent design, advanced parametrics brought the

project to the next level and an automated CNC process is completing the fabrication chain. BIM has increased clarity and project understanding throughout the project team and supply chain, resulting in faster cycle times and more automated higher-quality fabrication processes" (Witt, 2012).

2.2.2 Sutter Health

One of the most prevalent BIM integrated project delivery projects is the Sutter Health Eden Medical Center in Castro Valley, California, U.S.A. The owner, Sutter Health (SH) had to abide by California state-mandated code constraints. They needed to build a seismic compliant hospital facility to replace the original 55-year-old Medical Centre. In addition there was a stringent budget of $320 million and a five-year schedule from design through to occupancy. This forced the project team to rethink its delivery system method and fast track the project schedule. According to SH's senior project manager the project would take seven years to complete under conventional project delivery methods.

The owners implemented a groundbreaking integrated project delivery (IPD) contract between 11 organizations. This was put in place to ensure that a high quality project was designed and constructed on schedule and within budget (MHC, 2012). The team chose to use BIM throughout the project lifecycle. Project designers, engineers, contractors, and subcontractors were contracted early on in order to collaborate on precision prefabrication shop drawings and model coordination that would streamline project budget and schedules. The BIM models were created early on with critical building design elements emphasised. According to MHC (2012) over 25,000 BIM documents had been created by the time construction started. At any given time during the project, there were approximately 50 organizations that had 'real-time' access to all of the BIM documents.

Because of the integrated design model and bringing in the trades and subcontractors early on in the project, there were merely 555 requests for information (RFIs). This is 70% below the traditional baseline for RFIs on a project of this magnitude. The senior project manager makes note that, of the 555 RFIs, approximately 55% were mitigated the same day they were created. Furthermore, 20% of the RFIs were mitigated within several days. This was a result of the IPD systems put in to place. Additionally, all of the electrical conduit, piping, rebar, sheet metal and structural steel were all fabricated using BIM models. Suppliers and trades were able to preassemble building components prior to site delivery. They also used the model for designing and prefabrication of critical medical equipment, which is not the norm in a project of this magnitude yet proved to be a very successful activity. By establishing an integrated project delivery agreement and bringing the team in early, there was better communication resulting in a successful but challenging project.

2.2.3 China's Shanghai Tower

The Shanghai tower located in the Pudong district of Shanghai is planned to be completed in 2014 and will become the world's second tallest skyscraper. Due to the complexity of the core structure, exterior skin, green design, along with an international project team, the A/E team of Gensler, determined that the only way to achieve their goals were to implement BIM and integrated project delivery system from the very beginning of the project. The tower's iconic design is said to embody Shanghai's past, present and future. See Figure 3.

Figure 3 - Shanghai Tower amongst the Lujiazui Finance District Landscape

BIM implementation facilitated the design of the complex double independent glass curtain wall. Due to the extreme weather conditions in Shanghai, including typhoon force winds, wind tunnel tests of building models were performed resulting in the enhancement of the 120º degree spiral rotation that is said to reduce wind loads against the glass facade by as much as 24%, resulting in a construction cost saving of $58 million. The structural foundation and core design is said to withstand an earthquake of 7.5 magnitude on the Richter Scale. According to Pham (2012), the tower is made up of nine cylindrical sections that are wrapped around the core, spiralling upwards enclosed in a glass facade. There are numerous atriums and public spaces that house cafés, restaurants, gardens, a hotel and retail establishments. No matter where one stands within the structure, one will be will be able to see the city from every viewpoint. The building will host a rainwater recycling structure and wind turbines that are designed to generate approximately 350,000 kWh of electricity each year.

If it were not for BIM modelling, the design and engineering team would not have been able to conduct wind tunnel experiments and earthquake and structural simulations. The geometric component sizes and design data from the BIM enabled the engineers to extract this information for calculations and analysis. Furthermore, BIM gave the project the ability to visualize in 3-D, all of the building components; accelerate the design and construction process, design and model the tower efficiently, share project documents with electrical, mechanical and structural engineers, along with contractors, owners, subcontractors, fabricators and the supply chain, aid in the design and construction work flow, sequencing and better manage the construction cost and schedule. A new process for mechanical and electrical installation was created as a result of the BIM. Additionally, the owners are planning to use the model to manage building controls and systems and operate and maintain the tower upon occupancy. This is a huge investment for the building owners, which translates to a better return on investment and a longer building lifecycle. The BIM model will be turned over to the facilities manager and it is envisioned to aid the operation and maintenance of a more efficient environmentally friendly skyscraper (Pham, 2012).

The Tower, when completed, will be a green sustainable high performance facility with a geothermal system for heating and air conditioning. It will house wind turbines at the top of the tower that will power the park areas and exterior lighting. One-third of the site will be devoted to green space. The two glass spiral exterior curtain walls are designed to perform like a blanket insulating the structure and reducing energy consumption. Most building materials will be harvested and manufactured within in an 800 kilometre radius. The overall planning, design and construction of this complex high performance skyscraper would not have been possible without the collaboration of a BIM project delivery system.

2.3 Exploratory Research – Outcomes from the Submitted Questionnaires

Questionnaires were distributed to AEC academics and practitioners. The main function of this section is to gather viewpoints from a cohort of built environment professionals in order to promote a better understanding of the impact of BIM on the AEC community. The questionnaire comprised open-ended questions aiming at identifying key-aspects of BIM, their enablers and barriers. There is no basis for statistical generalisation given that the focus of this research is in the conceptual phase of discussion regarding the added value of BIM.

The participants from various countries were invited to partake in the research via e-mail. They are employed by a variety of AEC organizations, ranging from small to large companies in different business areas (i.e. design, project management, construction). The length of industry experience of the participants varied from 1 year to more than 30 years. Not all participants currently work with BIM, and the majority have not received formal/complete training in BIM, which seems to represent a norm for the construction sector. The participants, who answered positively that they have had BIM training, stated that their training sessions were full of commercialism about software and not the conceptual aspects of actually producing a BIM model. Finally, there seems to be a poor correlation between government policies and the adoption of BIM.

The following items present the main findings from the questionnaires.

a) Financial Implications

The participants reached a consensus regarding the financial implications of BIM. Its major financial advantage is clash detection, decreased rework, and the awareness of problems and information from early design to post-construction. BIM's major disadvantages have been related to the upfront costs for implementation (i.e. hardware and software) and the fact that "the effort/time to build the model is tremendous". In this context a paradox arises. In order to invest in BIM software, companies will need to believe in its capabilities and invest money and human time and efforts in order to implement it successfully. Nevertheless, such decisions produce short- and long-term financial implications according to the interviewees.

b) Non-financial Implications

BIM has been realised to be a solution for delivering better understanding about customers' requirements. In this context, the participants highlighted the point "work that is done right the first time - can be collaboratively delivered by all parties". Such collaborative environments have been referred to as one of the major aspects of BIM as well as the ability to test different situations and scenarios (fluid dynamics, structurally, wind flow) virtually. It is the opinion of the participants that BIM is very helpful at the post-construction stage, especially for facilities management purposes. Finally, it has been discussed by the participants that there is need for a better appreciation of BIM by customers, "while some clients say they want BIM they do not understand what BIM is and what it entails". In this sense, there is a demand for knowledge levelling about the capabilities of BIM to be promoted within the AEC community.

c) Productivity

It is the opinion of the participants that BIM has potential for increasing efficiency in construction. Nevertheless, the views diverge as "BIM is in its infancy" and therefore companies have different levels of BIM implementation. There is a view that BIM increases collaboration, fosters increased productivity and promotes better project delivery "if implemented properly". The participants positioned that rework is widely reduced as long as BIM is implemented, and "standard process and protocols require clarity and unification: interoperability of software and systems is imperative". Conversely, a set of respondents stated that it "will be necessary to track productivity rates over the medium term to learn how BIM has increased site efficiency". Such a statement raises the issue of performance management, and the need for metrics for assessing the process from early design to production. Additionally, some participants have indicated "the downside now is the cost of setting it up", which implies that short-term financial investments are necessary in order to have increased efficiency in the long run.

d) Sustainability

The use of BIM for promoting a more sustainable construction project faces different perspectives. On the one hand, there is a view amongst respondents that BIM produces low impact for increasing sustainable performance, "sustainability is about lifecycle" and BIM has been applied in discrete phases of the project. Other participants have pointed out that BIM is "a documentation tool" and that sustainable issues are more related to "materiality, engineering and design". Furthermore, the majority of the participants have agreed that BIM delivers increased sustainability. There is an understanding that BIM is related to waste reduction. For example "exact quantity take-offs mean that materials are not over-ordered". The BIM features (i.e. simulation) enable "analysis of building performance and gives the availability to quickly appraise options and the impact of the lifecycle, energy costs, etc., during the design stage and design analysis". Such simulation capability allows for continuous analysis of alternative components and construction systems that improves sustainable product delivery.

3 The Economics of BIM

In this section, the economics of BIM is discussed in terms of technology adaption, the practical impacts of BIM and the use of Total Factor Productivity as a means for calculating the Return of Investment of BIM projects is considered.

3.1 Technology Adaption

Attempts at measuring the effect of technology (i.e. ICT), on the productivity of an industry or organisation have often been fraught with problems, especially with the availability of data (Lehr and Lichtenberg, 1999; Ruddock, 2006; Sigala, 2004). This has prompted intense debate on the benefits that ICT adoption brings to an organisation or industry with regards to economic efficiency and productivity (Atzeni and Carboni, 2006; Quirós Romero and Rodríguez Rodríguez, 2010; Sigala, 2004). Yet according to

Underwood and Khosrowshahi (2012), the role of ICT has evolved from being a tool or utility to becoming a strategic asset for any organisation towards delivering business process improvement and value. ICT-based innovation is recognized as bringing productivity improvements and sustainable competitive advantage to industry. As well as socioeconomic development and growth due to their role in introducing and diffusing the concepts of knowledge sharing, community development and the promotion of equality (Underwood and Khosrowshahi, 2012).

The adoption of BIM has been heralded as an emerging technology that has the ability to create efficiencies within the construction industry by streamlining its processes and activities, fostering collaboration and sharing of accurate information. Apparently, these are the qualities ICT possesses. Thus BIM is akin to ICT. Companies consider ICT as a driver for process efficiency and an imperative enabler to facilitate flexible information processing and communications with its clients, consultants, and supply-chain partners (Sigala, 2004; Underwood and Khosrowshahi, 2012). As a result, the construction industry has invested heavily in ICT. On the other hand expenditure still remains relatively low when compared to other sectors (Ruddock, 2006; Underwood and Khosrowshahi, 2012). The benefits from investment and use of ICT in the construction industry are expected to show themselves as improved efficiency and productivity (Ruddock, 2006). Nonetheless a number of factors such as lack of awareness and training, fragmented nature of the AEC industry, industry's reluctance to change, hesitation to learn new concepts and technologies, lack of clarity on responsibilities and roles and risky and uncertain nature of investments have been identified as major barriers (Gu and London, 2010; Ruddock, 2006). Most significantly, economic conditions strongly affect ICT investment and vice versa (Ruddock, 2006; Underwood and Khosrowshahi, 2012). According to Ruddock (2006), rapid investment is usually accompanied by strong growth in productivity. Yet it takes time for the implementation of new technology to realise its full potential and the evaluation of the economic benefits for the construction sector is difficult to accurately determine due to data unavailability (Lehr and Lichtenberg, 1999).

3.2 Economic Impact of BIM

BIM is being employed across the globe on a variety of projects at various levels of adoption, and within various types of organisations from prime contracting and large consulting organisations to small architectural practices (Underwood and Isikdag, 2011). There have been remarkable uptakes with great enthusiasm in the USA, Australia, Netherlands and Germany (Ballesty *et al*, 2007; Young *et al*, 2009). Despite the initial inertia of adoption in the United Kingdom, BIM has started gaining traction due to its benefits (Waterhouse and Philp, 2013). A survey carried out in 2012 showed the percentage of the industry actually using BIM has grown to 39% from 13% in 2010 while the number of those who have not heard of BIM has reduced from 43% to just 6% over the same period (Waterhouse and Philp, 2013). This represents positive evidence of growth and acceptance of BIM in the U.K., which has been facilitated by central government policy and the requirements of the Government Construction Strategy (HM Government, 2012; Lorimer and Bew, 2011). At present, there is a real thirst for knowledge of how to plan not only for greater efficiency, but also for better assessment and improved collaborative processes. As the widespread adoption of BIM has seen a positive change in the way we communicate and collaborate, in turn this sharing culture enables informed and aligned processes (Waterhouse and Philp, 2013).

It has been argued that, for the BIM model to be successful, there has to be a paradigm shift from traditional silo disciplines of architecture, engineering and construction to a more collaborative management practice with specifics in process management, operations management and lean management. This can be captured by developing a workforce with enhanced skills, supported by information and knowledge technologies (Owen *et al*, 2013). Though achieving this is no mean feat, as any investment must be substantiated empirically in both economic and financial terms to quantify its benefits. Lehr and Lichtenberg (1999) argue that attempts to compute the economic benefit will need the collection of detailed firm or business unit level data in order to accurately measure the contribution of ICT as aggregate data have proven to be unreliable. On the other hand Ruddock and Ruddock (2011) argue on the contrary, that by carrying out a meso-analysis (the industry level analysis) of the construction industry's performance based on a detailed breakdown of factor inputs, the feasibility of developing an industry benchmark to permit comparisons for individual organizations can be considered. In addition, the issue of efficiency gain from the use of BIM in the construction industry may only be fully understood if measurement of usage could be improved (Ruddock, 2006). To this end several methods have been proposed to calculate the benefit of ICT in industry. These include:

- Total Factor Productivity (TFP) Method (Atzeni and Carboni, 2006; Lehr and Lichtenberg, 1999; Ruddock and Ruddock, 2011);
- Data Envelopment Analysis (Ruddock, 2006; Sigala, 2004).

For the purpose of this paper, only Total Factor Productivity (TFP) will be focused upon.

3.3 Total Factor Productivity

The construction industry can be characterised by the production of large complex and immovable products that contribute to the economy in terms of productivity due to levels of technology change, capital investments and labour utilisation. Its production process can be characterised by a technical relationship in which its inputs are transformed into outputs (Perman and Scouller, 2004). The level of technological innovation that facilitates the process, which determines it productivity, influences the rate of transformation of inputs to outputs. According to Slack *et al* (2007) productivity (P) is the ratio of what is produced by an operation or process to what is required to produce it. This can be depicted by the formula:

$$P=Q_t/Y_t$$

Where Q_t is the total output and Y_t is the cumulative multiplicity of all inputs. The technological innovation that influences this progress is termed Total Factor Productivity (TFP). This is the portion of output not explained by the amount of traditionally measured inputs used in production but a variable which accounts for other effects on total output (Comin, 2006). According to Diewert (2000), TFP is based on the real output produced by the firm or industry over a period of time divided by the real input used by the same set of production units over the same time period. It is a measure of an industry's long-term technological change or technological dynamism determined by how efficiently and intensely the inputs are utilized in production (Comin, 2006; Nishimizu and Page, 1982).

The economic benefit of BIM in the construction industry may perhaps be measured by determining the efficiency of the construction industry in relation to the total output. Efficiency is defined as the ratio of the total output to the total inputs of any system (Slack *et al*, 2007). Technology adoption and process improvement alter the variables involved in the production process, which influences the efficiency of an organisation or industry. Thus, TFP is derived as a residual and includes a host of effects such as improvements in technical efficiency, changes in returns to scale and mark-ups, as well as technological change (Comin, 2006; Hulten, 2001; Ruddock and Ruddock, 2011). Its levels are measured as the difference in outputs when differences in all inputs have been accounted for (Ruddock and Ruddock, 2011). This definition relates to the Cobb-Douglas production function model. According to Perman and Scouller (2004), a production function is used to identify the relationships between the firm's inputs and outputs that describe the maximum amount of output, which can be obtained, by using particular amounts of inputs given by the equation:

$$Q=f\,(X_1, X_2, \ldots, X_n)$$

Where the quantity of output *Q* is determined by the quantities used of various inputs *X1, X2…Xn,* which represent capital, labour and other factors of production. The Cobb-Douglas production function model indicates that outputs *(Q)* are an exponential function of the factors of the inputs capital *(K)* and labour *(L).*

$$Q=f\,(L,K)$$

According to Perman and Scouller (2004) production function inputs are substitutes for one another but they are less than perfect substitutes. Hence, they are not capable of determining the efficiency with which inputs are converted to outputs. Therefore a third function "A" must be introduced into the equation:

$$Q=A, f\,(K^{\alpha},L^{\beta})$$

Specifically "*A"* represents the efficiency with which inputs are converted into outputs, *Q*, and is a multiplicative technological parameter (Lehr and Lichtenberg, 1999; Perman and Scouller, 2004). The parameters, α and β, determine the impact of outputs in variations of both capital and labour respectively (Perman and Scouller, 2004). According to Lehr and Lichtenberg (1999), TFP can thus be defined as:

$$TFP \equiv Q/(K^{\alpha},L^{\beta})=A$$

The efficiency with which factors of production are converted to outputs is dependent on a factor of productivity that acts as an enabler to the production process. TFP is a key measure of the economic performance of an industry. It represents how efficiently the industry uses the resources that are available to turn inputs into outputs with the aid of technology or improved processes. Based on the equation, BIM as a technology and process may perhaps facilitate the productive efficiency of the construction industry by raising 'A', which makes all factors of inputs proportionately more productive (Lehr and Lichtenberg, 1999). To this end, it important that relevant data be collected from firms utilising BIM in the construction industry so that the productive efficiency can be measured. This will ultimately build upon the benefits of BIM within the industry and improve a greater adoption.

4 The Added Value of BIM

The discussion regarding the added value of BIM has been motivated by the current market competition and the need to deliver better projects efficiently. The value of BIM is presented in this section by highlighting the benefits for the design and construction project phases, investigating the links between lean and BIM, reducing the complexity of infrastructure projects, and exploring how companies building infrastructure projects have calculated Return on Investment (ROI).

4.1 Design and Construction Project Phases

The consideration of collaboration with the ability to share and exchange information within the AEC sector has been a long-term passion and desire for practitioners. As a result, numerous efforts have been put into action to achieve this. The drivers have been knowledge silos that exist within the AEC sector. In addition, the rigidity of the sector has led to the inevitable need for rapid innovation. This is as a direct result of issues involving budget overruns, delays, and sub-optimal quality in terms of project flexibility, end user's dissatisfaction, and energy inefficiency. According to Sebastian (2011), the lack of communication and coordination between the actors involved in the different phases of a building project is among the most important reasons behind these problems. Thus the processes for extraction, interpretation, and communication of complex information are often time-consuming and difficult. In order to solve this problem, BIM has been introduced as a driver for efficiency.

Interestingly several definitions of BIM exist and have been viewed from various positions. For example, Azhar *et al* (2007) defines BIM from a technical perspective as a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and to improve the process of delivering the facility. It represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility (Azhar *et al*, 2007). Shennan (2012) views BIM from a process management perspective as a coordinated set of processes, supported by technology, that add value by creating, managing and sharing the properties of an asset throughout its lifecycle by incorporating data (physical, commercial, environmental and operational) on every element of a development's design. On the other hand, Patrick *et al* (2012) presumes the data management perspective and advocates that the major strength of BIM is its ability to maintain a digital database that can be used together with other software in order to run simulations and deliver information to professionals. Then again, Underwood and Isikdag (2011) consider BIM as enabling seamless processes that support the complete lifecycle of the facility, embedding a model-based approach, full information coordination and management. Gu and London (2010) surmised that BIM is envisioned to achieve efficient collaboration, improved data integrity, intelligent documentation, distributed access and retrieval of building data and high quality project outcome through enhanced performance analysis, as well as multidisciplinary planning and coordination.

Thus, whichever position building information modelling is viewed from, there lies within the basic concepts of creating, sharing and managing data and information of an object in a format consisting of a digital and textual representation through a coordinated set of processes that add value to an asset throughout its lifecycle. Therefore, the design and construction phases of projects perceive significant value from the application of BIM.

4.1.1 BIM During the Design Phase

During the design phase the project scope, cost and schedule start to take shape. Any changes in project scope will have a direct impact on the cost and schedule. In a non-BIM project the designers may use a standard 2-D CAD drawing platform (AutoCAD) with a possible 3-D platform such as Revit. At this point in the project design, the CAD drawings are not linked to any specific schedule or cost method. According to Forbes

(2011), developing the budget and project schedule is a time-intensive activity and can be very complicated at the early stages of a project.

If BIM is introduced in the design phase (or prior to it), the cost and schedule become automatic. It can be linked together and any additions or changes to the project scope are registered in 'real-time'. The current design, cost and schedule are made available to all project stakeholders at any time, at any place. As the design progresses and takes shape, so does the cost and schedule in sync, saving practitioners time and money in having to develop the cost and schedule manually, in addition to struggling to capture all scope changes. The utilization of BIM models is said to speed up the design phase, construction documents and permit drawing development. Additionally, BIM communicates the design intent electronically creating 3-D renderings automatically that can be manipulated, if needed, and communicated to the client. This enhances the efficiency of the AEC team to communicate and sell the project design to the client (Forbes *et al*, 2011).

On the other hand, the designers must understand what they are designing and coordinate all efforts with the engineers, contractor and clients. The vaster the project team, the more integrated the project team needs to be. According to a Senior Architectural Designer with HDR:

> *"The biggest disadvantage is that the information used to develop the model needs to be fairly well understood before drawing too much. How to develop the model, how to link the model, etc. Once you have marched down the road with one way of developing the model a change is virtually impossible. The other big disadvantage is that when someone makes a mistake it affects everyone sometimes catastrophically causing hours of wasted time (bigger the team more time is lost) while the file is restored to the last place things were fine. If one is patient and builds the model with purpose and focus the ability to see complex relationships is greatly enhanced. The ability to add information and schedule is brilliant. Each is a huge time saver if built properly."*

In 2006, federal funding for B&W Pantex's new $100 million testing facility for the U.S. Department of Energy (DOE) (the client) was underway when funding issues inundated the project. Construction CAD documents were at 95% completion. Before start-up could occur, B&W Pantex hired CH2M HILL to develop and manage the BIM model on the project. According to B & W's project engineer, "BIM was an emerging technology" (MHC, 2012) and they had seen its success rate and lessons learned on other DOE projects. He goes on to state "we had been burned in the past by issues in the field and didn't want to relive those. It was worth trying it" (MHC, 2012).

It took CH2M HILL four months to develop the CAD model with a fee of $1 million. It paid off. They developed the model to the finite detail of ¾-inch conduit and found over 500 clashes, including 10 significant issues that would have cost B&W well over $10 million, a delayed schedule, lost labour and productivity and "rework in the field". Given that they invested the time and money to have CH2M HILL develop the model, they were able to get the project up and running and "back on budget". In view of the fact that CH2M HILL spent so much time in successfully producing the BIM model, they retained them to continue efforts on developing the BIM model throughout the rest of the project resulting in "accurate on-going as-built" drawing models (MHC, 2012).

As the project progressed, CH2M HILL was retained to validate utility stub-ups and steel rebar submittals. They found various issues such as missing stub-ups and stub-ups in the wrong location. Furthermore, there were missing rebar and inaccurate dimensions specified. In addition, the rebar shop drawings had been depicted inaccurately.

Later in the project, CH2M HILL spent time constructing a sequencing project schedule based on the BIM model. This aided the project team in monitoring the construction phases, weekly and monthly look-aheads and overall project progress (MHC, 2012). By bringing in a third party agent, such as CH2M HILL, later in the design process to develop the BIM model, B&W Pantex was able to not only save potentially millions of dollars, but there were also significant savings in the construction schedule and a continued 'real-time' as-built documented model.

The A/E 3-D model links well to the steel fabrication. This is big advantage for the structural engineers and steel fabricators. As soon as the design has been drawn, it does not have to be at 100% construction document phase. The BIM model can be handed over to the contractors for steel fabrication. The result would be fewer RFIs and potential change orders (PCOs), as well as significant clash detection savings. The contractors use the 3-D model to simulate the necessary construction activities and sequencing needed to complete the project on time and within budget. Forbes *et al* (2011) make note of significant savings on a project that eliminated approximately 12,000 structural steel details and drawings just by using 3-D design components.

As the design takes shape the cost and estimate is synchronised with the design development process. This can be very useful with fast track projects. BIM 4-D modelling enables the generation of actual quantities and bills of material. Furthermore, keeping all stakeholders updated on current 'real-time' cost and quantities.

4.1.2 BIM During the Construction Phase

Research has found that various construction firms are developing their own in house virtual design (VD) teams, also referred to as virtual design and construction (VDC) teams. Prior to the construction, once the architectural BIM model (A-BIM or A-model) is received, the contractors VDC team develops a construction model (C-BIM or C-model) that aids the contractors in quantity take offs for cost estimating the overall project. Integrating the cost estimate along with the project work breakdown structure, contractors can link the C-BIM to the overall master schedule. The A-BIM details can be translated into shop drawings and prefabrication instructions for subassemblies of building components such as casework, HVAC ductwork, pipes, sprinkler systems, plumbing systems and escalators to name a few. Additionally, clash detection simulations can be run, prior to systems development, fabrication and system installation. This eliminates translation interpretation issues from the A-BIM to the C-BIM reflecting in a cost-effective exercise for the contractors and owner/clients bottom line.

4.2 Lean and BIM

According to Schultz (2012), the intent of a lean philosophy is to enhance customer value, improve organizational efficiencies and reduce wasted efforts within all aspects of an organization, to include supply chain relationships, materials, inventory and technology. Evidence shows that lean implementation has been successful in manufacturing, aerospace industry, healthcare sector, IT sector, service industry, banking, public sector organizations and the construction industry. Though its origins grew out of the automotive industry, lean is applicable to any service industry and administration functions where process, procedures and systems are in place (Schultz, 2012). There is an array of construction organisations that have implemented lean as part of their project delivery system and can quantify its results as improving project performance, project budget, improved project schedule, and overall quality and profit.

When integrating Lean and BIM on construction projects, the project becomes focused on project delivery process efforts and the project team. According to Dave *et al* (2013) BIM is the "technological platform that acts as an enabling tool". Dave *et al* (2013) argues the theory that there has to be some type of balance in implementing BIM technology on a lean construction project. As shown in Figure 4, there is a balance of 40-40-20 amongst the project team, project delivery process and the technology utilized.

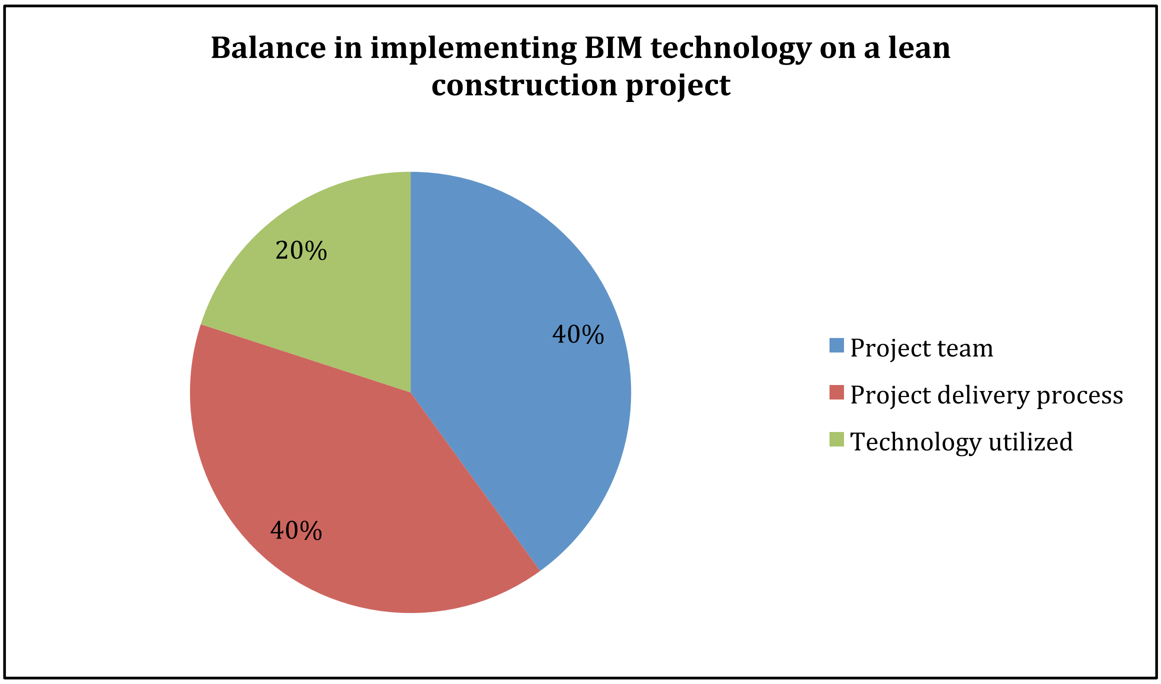

Figure 4 - Balance in implementing BIM technology on a lean construction project

With the economic climate uncertainty, the AEC industry, supply chain, owners and clients are looking at maximizing the economic value of their investment on construction project performance. By integrating Lean and BIM tools on construction projects, as indicated in Figure 5, where there is opportunity for efficiencies throughout project phases. The intertwining of lean and BIM facilitates collaborative planning, work ethics and provides a framework for new project delivery systems to be developed from the initial planning phase through construction, occupancy and operations and maintenance. It enhances the pull flow of design and construction activities providing the project team with a more thorough short-term and long-term monitoring and planning effort throughout the entire project lifecycle.

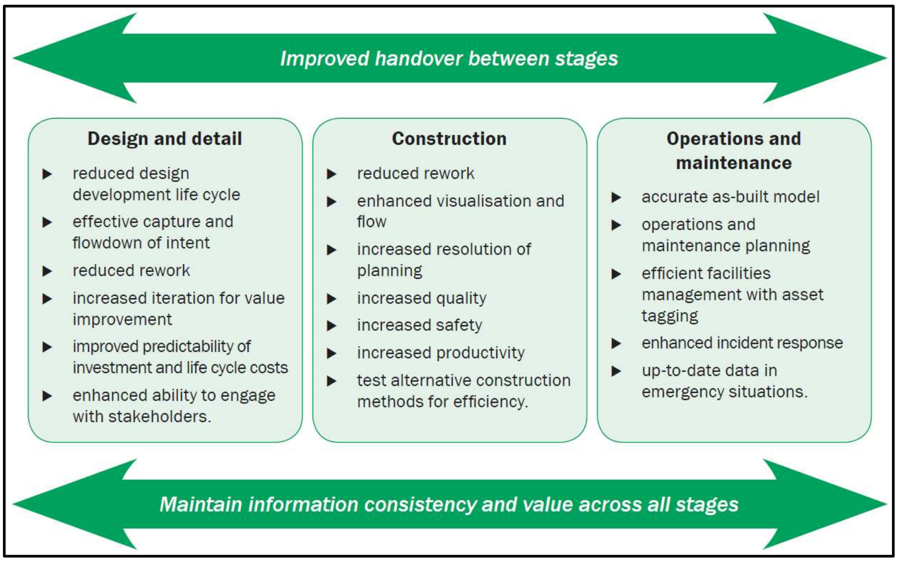

Figure 5 - Added Value of a Lean BIM Project at Various Phases
(Source: Dave *et al*., 2013 CIRIA C725)

It is more than an opportune time for clients in all construction industry sectors to seek out new proven technologies and efficient processes that will add value to the construction process, eliminating waste and errors thus improving overall quality, schedule and profit. Uniting BIM and Lean project delivery processes ensures a better quality product, ownership and team collaboration throughout the entire project life cycle.

4.3 Infrastructure

Typical infrastructure projects have an increasingly level of complexity not only in their intrinsic characteristics additionally in their impact on society. Usually, infrastructure projects are demanded by governments in order to improve the provision of services to a determined community. Airports, railroads (to include rail systems), highways, byways, bridges, and dams are examples of infrastructure projects.

In 2012, McGraw-Hill Companies produced a SmartMarket Report titled “The Business Value of BIM for Infrastructure: Addressing America’s Infrastructure Challenges with Collaboration and Technology”. This study found that 46% of the infrastructure organizations in the U.S. are currently using BIM technologies and processes in their project portfolio. This number presents an impressive growth rate, given that only 27% of the companies reported were using BIM two years ago.

Nevertheless, the use of BIM for infrastructure appears to be three years behind its use on other project types. Figure 6 and Figure 7 below present the lag in experience with BIM for infrastructure projects, in which the level of BIM expertise for all projects types is compared with infrastructure projects. The level of expertise reported by A/E, contractors, and owners is significantly lower in infrastructure projects when compared to all other project types.

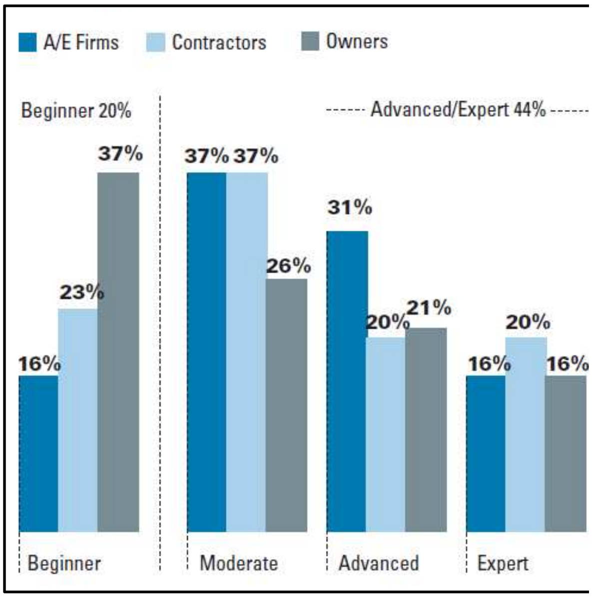

Figure 6 - BIM expertise: all project types
(Source: McGraw Hill Construction Report, 2012)

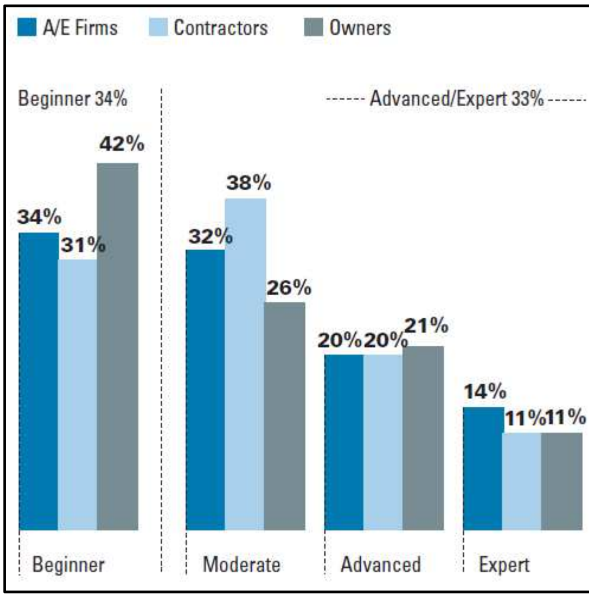

Figure 7 - BIM expertise: infrastructure projects
(Source: McGraw Hill Construction Report, 2012)

There is an increasing growth rate of BIM implementation in infrastructure projects as a whole. Such expansion is concentrated in water, public parks and recreation projects. On the other hand, the growth rate for dam projects presented the lowest growth rate. Figure 8 presents the BIM implementation in different infrastructure projects for results observed over the previous three years, and predictions for 2013.

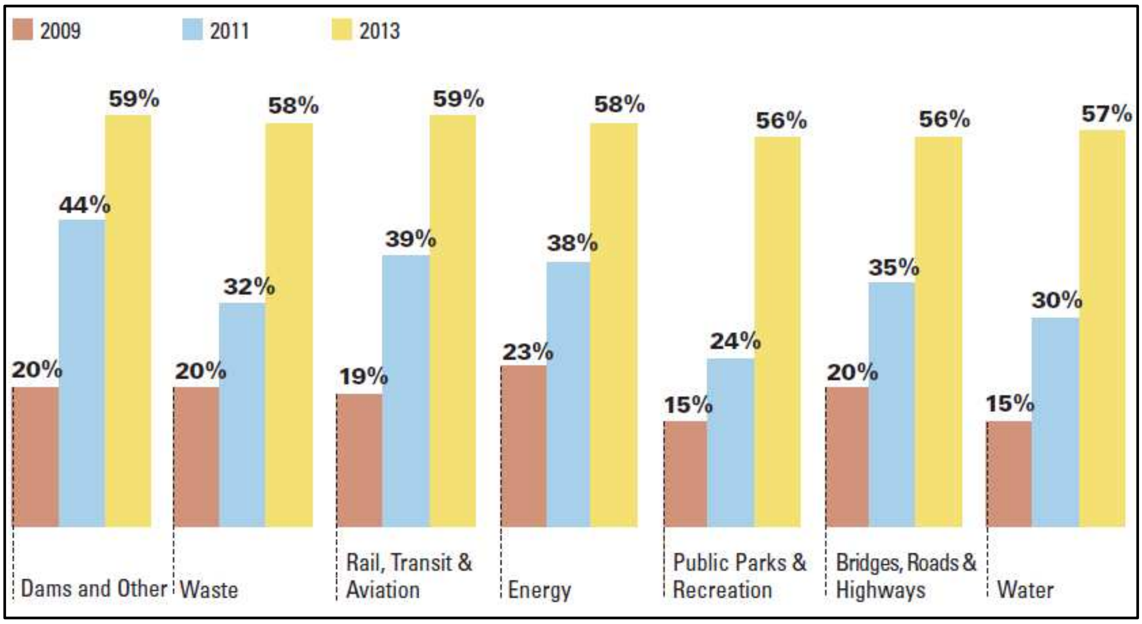

Figure 8 - BIM implementation in different infrastructure projects

(Source: McGraw Hill Construction Report, 2012)

Finally, there is an increasingly growth rate of BIM implementation for infrastructure projects in all organization sizes. Table 2 presents the criteria for defining different organization sizes.

Table 2 - Criteria for defining the organization size

(Source: McGraw Hill Construction Report, 2012)

Organization Size	A/E Firm Billings	Contractor/Owner Organization Revenue
Small	< $500,000	< $25 Million
Small to Medium	$500,000 to < $5 Million	$25 Million to < $100 Million
Medium to Large	$ 5 Million to < $10 Million	$100 Million to < $500 Million
Large Organization	$ 10 Million and over	$500 Million and over

There is an increasingly growth rate of BIM implementation for infrastructure projects in small and midsize organizations. For 2013, small organizations tend to have the highest level of implementation, which is attributed to the shorter cycle that their projects usually have. A summary of BIM implementation and predictions for 2013 according to organization sizes is presented in Figure 9.

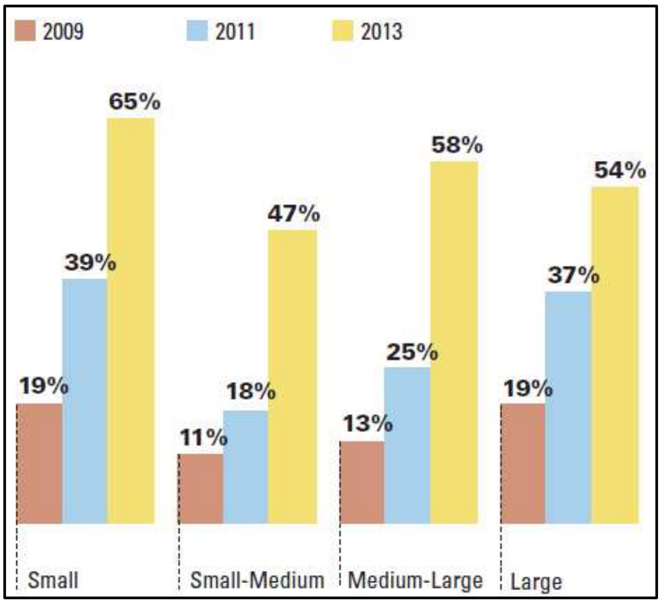

Figure 9 - BIM implementation by size of organization

(Source: McGraw Hill Construction Report, 2012)

The following benefits have been associated with the implementation of BIM for infrastructure projects: reduction of conflicts and changes during construction, reduction of rework driven by a BIM's project-oriented basis and improvement of productivity in projects. From the aforementioned benefits, a summary of business value of BIM for infrastructure is presented in Figure 10.

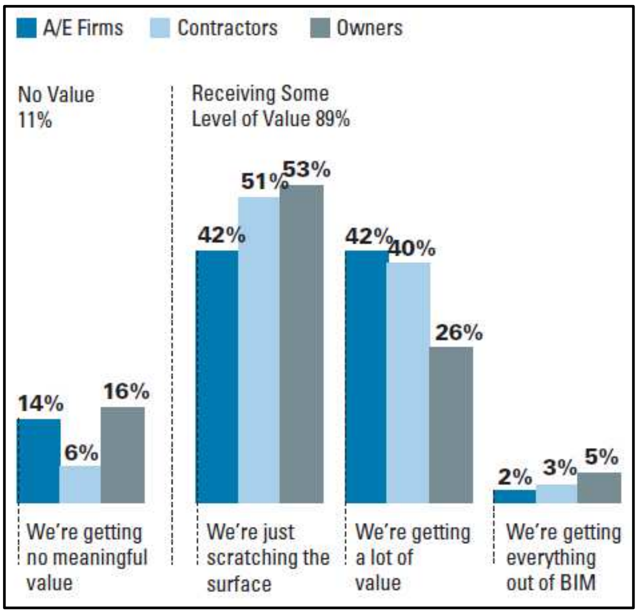

Figure 10 - Business value of BIM for infrastructure

(Source: McGraw Hill Construction Report, 2012)

On the one hand, A/E companies and contractors using BIM for infrastructure projects have highlighted a set of internal benefits as shown in Figure 11. The use of BIM has been reported as an important competitive advantage, once firms indicated BIM capabilities as enablers for winning new work. Reduced errors in construction documents and improved learning for younger staff have been reported as relevant benefits for A/E firms and contractors as well.

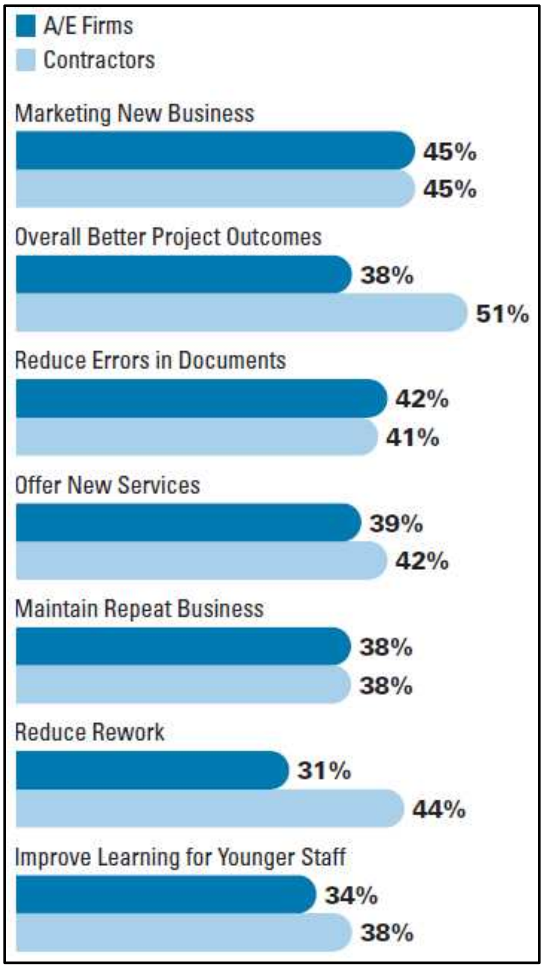

Figure 11 - Business benefits of using BIM for infrastructure projects for A/E firms and contractors

(Source: McGraw Hill Construction Report, 2012)

Alternatively, owners have highlighted the benefits presented in Figure 12. Such benefits include overall better project outcomes and reduction of rework as top internal business benefits for owners. Nevertheless, cost reduction in construction has been positioned as a low-ranked factor due to the difficult in consistently linking cost reduction to the use of BIM for infrastructure projects.

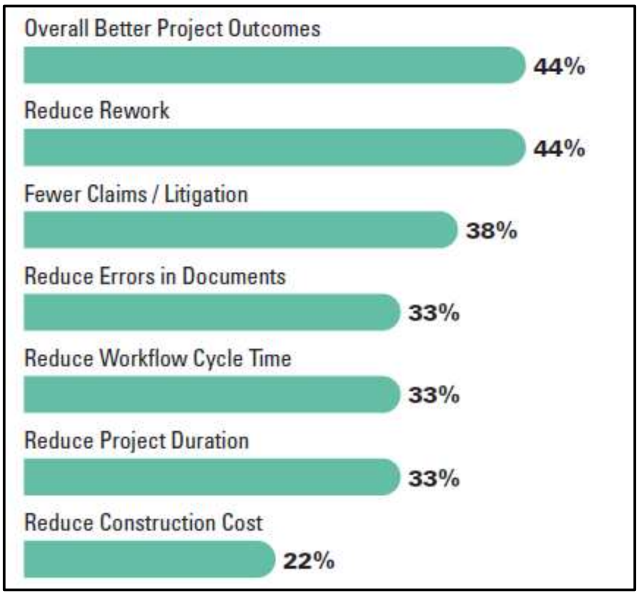

Figure 12 - Business benefits of using BIM for infrastructure projects for owners

(Source: McGraw Hill Construction Report, 2012)

A set of benefits has been mapped for BIM implementation in infrastructure projects. Such benefits are categorised by project phase, project process, and project factors. A comparison between such benefits is shown in Figure 13.

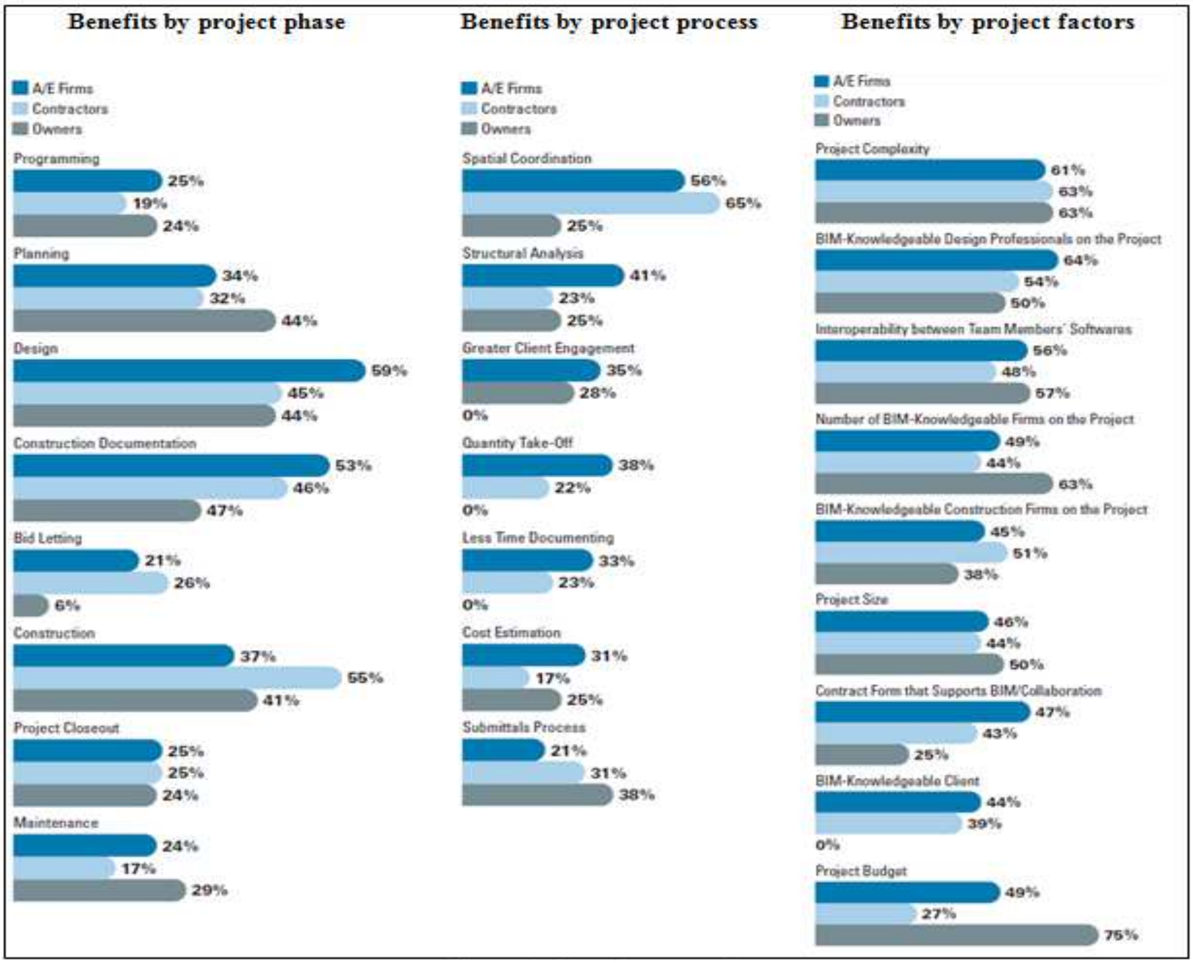

Figure 13 - Benefits comparison

(Source: McGraw Hill Construction Report, 2012)

Firstly, this study has found that BIM is still improving its applicability throughout the project lifecycle. In this context, the benefits do not show equal levels of realization along the project. The design and construction documentation phases show the higher levels of BIM value for infrastructure projects. Conversely, programming, bid letting, and maintenance present the lower levels of benefits by phase.

Secondly, it has been found that BIM generates diverse degrees of value for each player across project processes. Spatial coordination has delivered the highest level of value in the different project processes, with 65% positive responses from contractors. Conversely, quantity take-off, cost estimation, and less time documenting have presented lower levels of realized benefits when compared to other project processes.

Thirdly, there are important infrastructure project factors that add value to BIM use. In this context, project complexity plays a major role as a project factor related to value provided by the implementation of BIM. Conversely, among the most important project factors, BIM-knowledgeable clients presented the lowest level of impact in adding value to BIM usage.

It is noteworthy that better multi-party communication has been pointed out as the most important factor to be continuously improved in order to increase the value of BIM. In this context, seizing the collaborative work environment provided by BIM appears to be an efficient tool for adding value to project delivery.

4.4 ROI of BIM in Infrastructure Projects

Although there is no widely accepted way to calculate ROI on BIM, an increasing number of organizations (56%) reported that they are formally measuring the ROI of BIM. Additionally, 67% of the surveyed contractors reported a positive ROI of BIM and 26% reported a ROI higher than 25%, as shown in Figure 14.

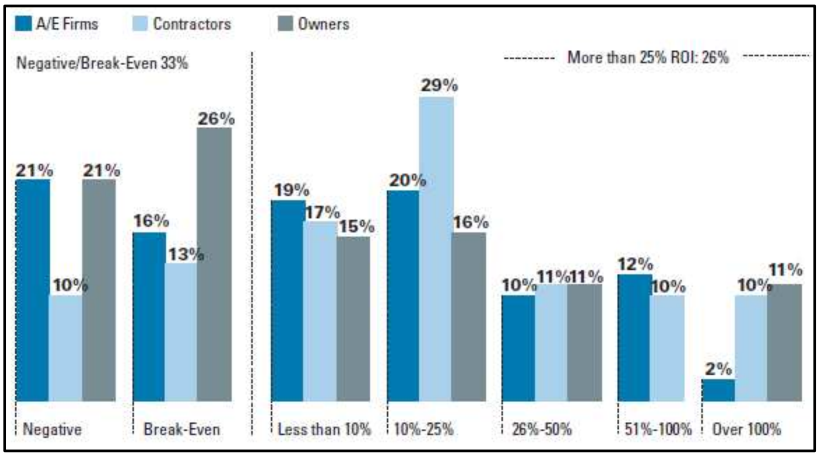

Figure 14 - Perceived ROI on infrastructure BIM investment

(Source: McGraw Hill Construction Report, 2012)

The majority of the companies that are not currently using BIM are interested in measuring ROI eventually. Nevertheless, such companies demonstrated that they do not have any definitive schedule for doing so as shown in Figure 15.

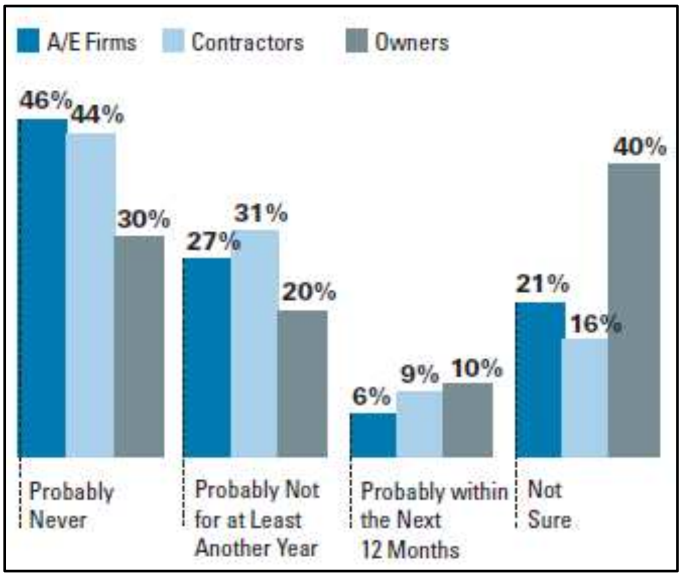

Figure 15 - Measurement of ROI on BIM for infrastructure projects in the future

(Source: McGraw Hill Construction Report, 2012)

A list of important means of improving ROI on BIM for infrastructure projects has been developed: improved project process outcomes, better multi-party communication, improved productivity, and positive impact on marketing, among others. Such means support the idea that better project processes generates significant benefits for individual participants.

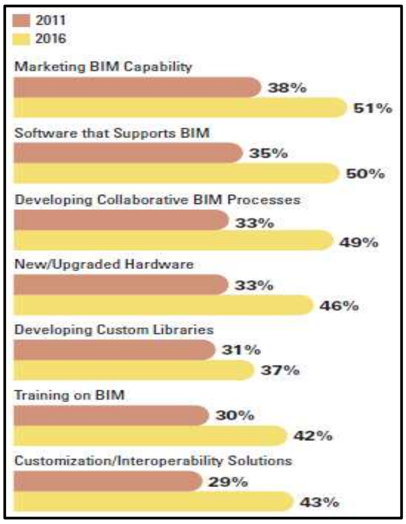

Figure 16 - Focus of BIM infrastructure investments

(Source: McGraw Hill Construction Report, 2012)

Finally, the focus of BIM infrastructure investments has been predicted to be concentrated on improving the marketing of BIM capabilities, the development of software that support BIM, and the expansion of collaborative BIM processes as shown in Figure 16. Although the improvements in software and hardware are prerequisites, the improvement of inter-company processes enables increasing value generation.

5 Conclusion

This report has disseminated the impact of BIM on the global construction sector and AEC community, as well as having explored the global perspective of BIM. It has studied the added value of BIM implementation in the main project phases, in the interfaces between Lean Production and BIM, in the complexity of infrastructure projects, and in the Return on Investment (ROI) for companies adopting BIM. What this report has not been able to provide is evidence of how the AEC community actually measures the total economic value of BIM, its technology and relationship on the construction sector and society. In Section 3 of this report, the concept of Total Factor Productivity (TFP) has been introduced as a potential key measurement tool for the economic performance of BIM. It is the conclusion of this report that future research is explored more fully on this subject, as noted in Section 5.2 below.

In brief, BIM as a philosophy and technology provides the user with a visual perspective of the entire construction project performance from initial project planning, design, through construction, owner occupancy and operations and maintenance of facilities. The one most valuable characteristic and benefit of BIM is that the model provides visual representation of project components in 'real time' over the course of the project lifecycle. Any one project stakeholder - vendor, engineer, fabricator, contractor or owner - has access to current 'real time' project data, anywhere, at any time. Additionally, improved multi-party communication becomes another important added value factor if a BIM project delivery system is introduced.

Evidence concludes that there is widespread use of BIM throughout the AEC industry and with U.S. and U.K. government regulations and standards being put in place, their influence will result in more awareness, leaner processes, more collaborative process delivery systems and more efficient successful construction projects globally. The report has shown where the BIM model adds benefit and value to complex projects by keeping the cost, schedule and quality control efforts on target. BIM project delivery processes, when used correctly, have been proven to provide the ability to visualise all building components, accelerate design and construction phases, design and model facilities more efficiently, share project documents with electrical, mechanical and structural engineers, along with contractors, owners, subcontractors, fabricators and the supply chain, aid in the design and construction work flow, sequencing and better manage the overall construction cost and schedule. This report concludes that it is the "I" in BIM that creates the integration between the computer models, software interoperability, project requirements and specification, stakeholders, and the overall economic and added value impact of BIM on the construction sector and society.

5.1 Discussion

The competitive advantage of BIM project delivery implementation for the construction sector and society is based on the reduction of conflicts and component clashes, the ability to make changes during construction, aid reduction of rework and improve the overall productivity. There is evidence of a reduction in errors in construction documents and improved learning for younger staff has been reported as relevant benefits for AEC organizations.

On the other hand, in a recent industry report, owners highlighted the main internal business benefits that add value to the owner is the project outcome and reduction of rework. Furthermore, cost reduction is ranked low. Subsequently, it is a complicated task to actually link cost reduction indexes in relationship to the use of BIM project delivery systems. Nonetheless, through the use of BIM, team members have a better understanding and the ability to work through RFIs, submittals, PCOs, and clash detection more efficiently resulting in faster cycle times and more automated high quality fabrication processes. Overall, there is evidence that construction firms that have implemented a BIM project delivery system can quantify improvements in overall communications among stakeholders, project performance, project budget, project schedule and quality.

The technical benefits and added value of using BIM have been reported as reduced errors and omissions, improved functionality and software interoperability, less rework, better workflow cycle time and a reduction in cost, schedule and claims. Additionally, the overall advantage to the organization comes in part from an increase in profit; repeat business and business development, an offer of new services and fewer claims and litigation.

5.2 Future Research

It is proposed that future BIM research in economics and added value should be forthcoming in the area of developing a national formula to calculate the ROI and added value of BIM project delivery systems. Section 3 of this report introduced the concept of Total Factor Productivity. TFP represents the measurement of inputs into outputs of activities with the aid of technology or improved processes. Currently, there is not evidence of consistent recorded data of BIM internal and external company best practices between projects, industry, nations and governments. The effort required to produce such data will be an immense endeavour. Yet, once BIM ROI evidence can be provided for the client and project stakeholders, then the real economic and added value and benefit for achieving BIM project delivery systems on the AEC community and society can be fully realized.

To this end, it important that relevant data be collected from firms utilising BIM in the construction industry, so that the productive efficiency can be measured. This will ultimately build upon realisation of the economic benefits and added value of BIM on the construction sector and society by increasing a greater adoption of BIM project delivery systems.

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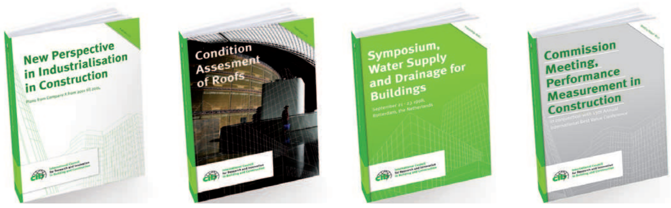

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