EXPLORING THE SYNERGIES BETWEEN BIM AND LEAN CONSTRUCTION TO DELIVER HIGHLY INTEGRATED SUSTAINABLE PROJECTS

Md.Afjalur. Rahman[1], *Vicente.A. Gonzalez*[2], *Robert Amor*[3]

[1]PhD student, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand.

[2]Lecturer, Department of Civil and Environmental Engineering, The University of Auckland, New Zealand. E-Mail: v.gonzalez@auckland.ac.nz

[3]Professor and Head, Department of Computer Science, The University of Auckland, New Zealand. E mail: trebor@cs.auckland.ac.nz

Mrah092@aucklanduni.ac.nz

ABSTRACT

Sustainable Construction has been acknowledged as a driver for societal transformation. However the practice of Sustainable Construction has not flourished yet as expected due to the discipline fragmentation over the entire project life cycle. Current research exhibits adversarial and non-collaborative behaviours in the different Sustainable Construction approaches adopted for delivering Sustainable projects. As a result it is claimed that an "Integrated approach" is imperative to eliminate the current limitations for delivering Sustainable projects. It is argued that Building Information Modelling (BIM) and Lean Construction have the potential to achieve Sustainable goals in a highly integrated fashion. Thus, their integration with Sustainability can be explicitly considered. BIM has comprehensively covered different Sustainability issues such as energy efficiency, optimum resource consumption, process visualization in an integrated way through collaboration with different stakeholders. On the other hand, Lean Construction is a production management philosophy that seems to suit Sustainability principles in terms of waste minimisation, resource optimisation, continuous improvement, resource end- user satisfaction, target costing and so forth. Moreover different research contended that the action of BIM, Lean and Sustainable Construction are mutually supportive and synergistic. In this regard, this study explores an integrated approach at conceptual level that links BIM and Lean Construction to uphold Sustainable principles over the entire life cycle of a project.

Keywords: BIM, Integration, Lean Construction, Project Delivery, Sustainable Construction

INTRODUCTION

Sustainable projects are often bounded by complex processes which are unusual for stakeholders (e.g. owners, designers, constructors). The process of delivering Sustainable project requires more design iterations, advanced simulations, analyses, additional site precautions, and the use of new and unfamiliar materials, which are typically more complicated considering traditional projects (Pulaski et al., 2006). Collaboration among different stakeholders and transparency in status, goals and rules are crucial for Sustainable projects (Klotz and Horman, 2010). Also, project management issues and government regulations become more complex to the implementation of Sustainability in construction (Marchman and Clarke, 2011). The current lack of awareness and understanding of Sustainability among clients, designers, constructors, regulatory authorities, businesses, and the general public also act as barriers for Sustainability (Long and Failing, 2002). On the other side, the existing systems on Sustainable practice collapse or fail to acknowledge the convenient project delivery method and principles that are scientifically crucial to enable Sustainable outcomes (Korkmaz et al., 2010).

In order to overcome these limitations, the Architecture-Engineering-Construction (AEC) industry is looking for comprehensive tools and methods to manage and deliver Sustainable projects (Marchman and Clarke, 2011).Best practices to guide Sustainable design and construction are highly needed for today's contractors. But unfortunately the current research undertaken to overcome these barriers and convey Sustainable outcomes is insufficient (Marchman and Clarke, 2011). However, the combined effect of technology and effective management practices can bring more effectively Sustainability goals into projects (Pommer et al., 2010). Therefore, the authors claim that the concurrent use of BIM and Lean Construction can enable a more effective and highly integrated delivery process of Sustainable projects in the AEC industry. In this regard, BIM as an AEC technological advancement plays a vital role in Sustainable projects by encompassing detailed information about how a facility should work (Bynum et al., 2012). Otherwise, Lean Construction helps to integrate Sustainable values into traditional projects by maximising value and minimising waste (Huovila and Koskela, 1998). It is also recommended the integration of three drivers, i.e. BIM, Lean and Sustainable Construction; bearing in mind the current Sustainable challenges (Koskela et al., 2010). However, not much research has been undertaken to integrate BIM, Lean Construction and Sustainability in the AEC industry. Therefore the aim of this paper is to explore an integrative framework of BIM, Lean Construction and Sustainable Construction, and its potential to deliver highly integrated Sustainable projects.

SUSTAINABLE CONSTRUCTION

Modern world suffers from different political, social and environmental problems which create a risk of the destruction of mankind (Kibert, 2008). In the last few decades, a general awareness about these problems has arisen, and as a result, the concept of Sustainable development has been established (kibert, 2008). According to the World Commission on Environment and Development (WCED) "*Sustainable development is the development which meets the needs of the present without compromising the ability of future generation to meet their own needs* (Chaharbaghi and Willis, 1999)". Also, Sustainable development can be understood as "*a process which enables all people to realize their potential and improve their quality of life in ways that simultaneously protect and enhance the Earth's life-support systems* (Parkin, 2000)". Sustainable development comprises of three major aspects: social, environmental, and economical, which are instrumental for the societal transformation and are known as the 'triple bottom line' (Kibert, 2008).

The construction industry has a key role on the built environment and is also the largest contributor in terms of environmental, economic and societal impacts (Horvath, 2004). Therefore, Sustainable development should be a major driver for the construction industry in order to change its business and production approach to deliver projects. Sustainable construction is a subset of Sustainable development, which can be defined as a construction process which incorporates the basic goals of Sustainable development (Chaharbaghi and Willis, 1999). Thus, Sustainable construction should be based on environmental responsibility, social awareness, and economic profitability that enhance societal value in the built environment and facilities for people (Langston and Ding, 2001).

BUILDING INFORMATION MODELLING (BIM)

AEC industry has a long quest on techniques that decrease project cost, increase productivity, quality, and reduce project delivery time. Building Information Modelling (BIM) has received much attention from academia and industry due to the fact that BIM has the potential and capabilities to achieve these performance improvements in the AEC industry (Azhar et al., 2008). BIM is defined as a virtual representation of all disciplines, and systems of a project within a single, virtual model, allowing all team members (owners, architects, engineers, contractors, subcontractors, and suppliers) to collaborate more accurately and efficiently compared to traditional projects (Azhar, 2011). Eastman et al., (2008) defined BIM as "*a verb or adjective phrase to describe tools, processes, and technologies that are facilitated by digital machine readable documentation about a building, its performance, its planning, its construction, and later its operation"*. BIM is also a virtual model of a building that contains precise

geometry and data for getting optimum design, procurement, fabrication and construction activities required for a project (Eastman et al., 2008).

BIM software has intelligent capabilities such that any change in the design process simultaneously takes place all over the model and its corresponding documents. BIM allows a building to be built virtually prior to construction of the real facility, which creates an opportunity to check constructability in the real world and minimise drawbacks or any uncertain issues during the entire process. As a result, it improves efficiency, optimise resource by limiting environmental waste (such as energy, water, material etc) and enhance passive design strategies (Bynum et al., 2012). Moreover, BIM has the potential to integrate and incorporate individual stakeholders in a platform, which is crucial to remove discipline fragmentation for AEC projects (Krygiel and Nies, 2008).

LEAN CONSTRUCTION

Lean Construction is a production management philosophy for construction adapted from “Lean Production”, which was originally developed for manufacturing. The root of Lean Production is linked with a Japanese word named “muda” which means “waste”, i.e; any human activity that utilizes resources but creates no value. Taiichi Ohno a Japanese engineer in Toyota first thought about waste while visiting Ford Motor industry in 1950. He recognized that seven types of waste in the production industry were destroying productivity. Ohno categorized these waste as (1) over production; (2) transportation; (3) motion; (4) waiting; (5) over processing; (6) inventory; (7) defects. As an antidote or remedy of ‘muda’, Ohno, introduces “Lean Thinking” that creates a way to specify value, arrange value creating actions in a sequence focusing on customer satisfaction (Abdelhamid et al., 2008; Koskela, 1992).

Womack et al. (1990, 2005) stated that ‘*Lean Thinking is a management philosophy that provides a way to do more and more with less and less human effort, less equipment, less time, and less space while coming closer and closer to providing customers with exactly what they want. It also intends to get the right things, to the right place, at the right time, in the right quantity while minimizing waste and being flexible and open to change’*. In contrast the collapse of the conceptual management models (time-cost-quality trade off, work breakdown structure, critical path methods, and earned value) to deliver projects on the mantra of 'on-time, at budget, and at desired quality' is now proven in the AEC industry (Abdelhamid et al., 2008). Therefore AEC academics and professionals have been revisiting conventional management in an effort to deliver better value to owners while making real profits in the AEC industry. Koskela (1992)’s seminal report identified the dissemblance between the conceptual models of construction management and the reality in projects which is signalled for the emergence of a comprehensive theory of

production management in construction. Hence, Koskela introduced a new management philosophy named as Lean Construction inspired by Lean Thinking (Abdelhamid et al., 2008). According to Koskela, the stand out definition for Lean Construction is, "*a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value* (Koskela et al., 2002)".

LEAN CONSTRUCTION AND BIM LINKAGE

Lean Construction and BIM are different approaches that have had profound impacts in the AEC industry. However, their synergy and potential for the AEC industry have been recently identified. In fact, Sacks et al., (2010) argued that an integrated approach of BIM and Lean can bring the full potential of their implementation in projects by an integrated project delivery approach (Sacks et al., 2010). Liker (2003) stated that Toyota integrated information and communication technology (ICT) which were needed for the development of organizational infrastructure, people, process, and other ICTs. Similarly BIM provides this opportunity to the AEC industry in order to improve process, people and productivity through binding the core construction processes. BIM and Lean Construction have been researched extensively in recent years, but their integration has not flourished yet as expected (Sacks et al., 2010). However, some researchers have achieved successful implementations of both BIM and Lean Construction (Khemlani 2009, Eastman et al., 2008,). Khemlani (2009) and Eastman et al., (2008) researched Sutter Health Castro Valley Medical Centre project and Camino Medical Centre and they found that BIM and Lean workflows were successfully integrated together for improved productivity and Sustainability. The most illustrative work about the BIM and Lean linkages has been done by Sacks et al., (2010) by developing an integration matrix of BIM and Lean Construction. They identified 56 positive and synergistic interactions between BIM and Lean Construction.

Although Sacks et al. (2010) form a BIM/Lean conceptual framework to illustrate the interactions between new information technologies and the production systems related to the AEC industry, this research is conceptual and stimulates further research. It is expected that further research bring more empirical evidence of the BIM/ Lean interaction which is a dire need for a productive and Sustainable AEC industry. Nevertheless, the current understanding of the mechanisms identified strongly supports the synergy between BIM and Lean.

LEAN AND SUSTAINABLE CONSTRUCTION LINKAGE

Lean Construction supports Sustainability principles mainly in three ways. First, waste reduction along with reduced material and energy waste in construction and maintenance (Koskela and Tommelein, 2009). Second,

reduction of harmful emissions by Lean processes (King and Lenox, 2001). Third, considering value, Lean product development for achieving challenging targets which can also be used to achieve Sustainability targets (Lapinski et al., 2006). Martinez et al., (2009) also illustrated a conceptual integration of Lean Construction and Sustainability supporting the synergies between both approaches.

Ahuja (2012) clearly demonstrates that Lean Construction tools and principles directly support Sustainable Construction principles. Integrated Design (Whole system design), Design for Maintainability (DFM), Set-based Design, Target Costing are Lean approaches worthy for achieving minimum environmental impacts and energy consumption during construction of Sustainable facilities. Lean Assembly or Prefabrication is one of the most successful methods that extensively support Sustainable Construction. Lean Production principles are recognized to reduce waste and sequencing processes in highly complex and production manufacturing environments. Through adopting Lean principles, the goal for shortened lead times, reduced costs, and improved delivery of Sustainable features can be achieved at a large scale (Lapinski et al., 2005). Moreover *"Lean and green (sustainable) construction shares a common goal, to eliminate as much waste as possible. Therefore, not producing waste is both the most efficient and cost-effective approach to achieve Sustainable goals* (Nahmens, 2009)".

It is argued that Lean Construction offers the conceptual basis, methods and tools which have great possibilities to faster Sustainable Construction (Huovila and Koskela, 1998). Therefore Sustainability in a project can be achieved by applying Lean principles because they not only provide the economic value to the process, but can also improve the social and environmental value (Ahuja, 2012).

BIM AND SUSTAINABLE CONSTRUCTION LINKAGE

Sustainable projects are rapidly adopting BIM to achieve Sustainable goals in a drastic way (McGraw-Hill Construction, 2010). More over many Sustainable Construction practitioners believe that Sustainability and BIM have synergies. Smart Market Report (2010) shows that around 27% AEC people believe that BIM has high potential to achieve Sustainable goals and around 49% believe BIM has a significant influence to get Sustainable projects.

The mutual relation between BIM and Sustainability comes up mostly in the design stage considering Sustainable features. Most Sustainable features are not tangible and require abstract calculations for their assessment (e.g. through the use of computational flow dynamics). The ability to make such evaluations rapidly enhances design towards Sustainable targets (Koskela et al., 2010). BIM tools have shown outstanding performance in energy simulation, day lighting simulation for

building layout and orientation, and HVAC (Heating, Ventilation and Air conditioning) analyses for better Sustainable solutions. Due to these analyses, requirements for heating, cooling, ventilation and electrical loads will cut off at large scale (McGraw-Hill Construction, 2010). The Palomar Medical Centre West (2007-2011) is a good example of mutual relation between Sustainable Construction and BIM. At its early stage, designers took a holistic Sustainable approach that involves nature as much as possible in the building including energy and water savings. In order to achieve their goals, they shared the common vision to all the project stakeholders and found that BIM was the platform to this integrated approach to get the Sustainable features. In order to emphasise the BIM impacts on Sustainable projects, Frances Moore, AIA, LEED AP, CO Architects associate principal stated that, "*You could design a Sustainable building without BIM. But what you cannot do is design and construct it in a truly Sustainable way that goes above and beyond the traditional approach, such as use of LEED checklist or the Green guide for health care* (McGraw-Hill Construction, 2010)".

Literature also supports a strong relationship between BIM and Sustainable Construction (Koskela et al., 2010). BIM is instrumental to get Sustainable design but its influence in others project stages (e.g. planning, construction, post construction) is not fully understood and exploited. Therefore, it is a matter of further exploration to identify the potential of BIM in other construction stages bearing in mind Sustainability.

INTEGRATION OF BIM AND LEAN CONSTRUCTION TO DELIVER HIGHLY INTEGRATED SUSTAINABLE PROJECTS

In general, BIM, Lean Construction and Sustainable Construction are individual and self-supported concepts, but they have a relative interaction and synergy. *BIM-Lean Construction*, *Lean Construction-Sustainable Construction*, and *Sustainable Construction-BIM* interactions have been also studied independently (Martinez et. al., 2009; Sacks et al., 2010; McGraw-Hill Construction, 2010). However, recent research has shown the potential to integrate the three concepts together and introduce a *BIM-Lean-Sustainability* approach in the AEC industry. Pommer et al., (2010) introduced this relationship through a conceptual building delivery method for healthcare facilities by integrating these three approaches. Moreover, it has been argued that the full potential of Sustainable Construction, Lean Construction and BIM can be achieved only when they have an integrated approach (Pommer et al., 2010).

According to Koskela et al., (2010) Lean Construction, BIM and Sustainable Construction play the role of production, representation and requirement of a product. Koskela et al., (2010) also depicted that these three approaches have synergies each other which can be an opportunity to change the paradigm of the AEC industry. It has been claimed by them

that "*regarding academic research, it seems that these developments have offered a surprise: the reorientation of academic research in view of the new situation started somewhat slowly. Nevertheless, profound changes are always excellent opportunities for relevant research to be done, and now promising signs of a renaissance of construction management research are already visible* (Koskela et al., 2010)".

Pommer et al., (2010) conceptually integrated BIM, Lean and Sustainability but the concept was developed considering healthcare facilities planning and early design stage. The limitation of this work can be related to the integration of selective principles that are worthy only for healthcare facility and not clearly focused to the whole life cycle of the project. On the other hand Koskela et al., (2010) investigated the mutual relation of BIM, Lean and Sustainability. Their work highlight only on the collaborative practice of these approaches while other issues such as a general framework for this integration has not yet been addressed. Looking into constrains of Sustainable practice (discussed in the Introduction section), an integrated approach of these three approaches is instrumental for the AEC industry. The contemporary advancement in practice through the integration of *"BIM-Sustainability", "Lean-Sustainability" or "BIM-Lean"* is acknowledged to a certain extent. In order to recognize the supportive action of a full integration, this research suggests an integrated framework for BIM-Lean and Sustainable Construction.

The core concept of this integration is to find the relationship among BIM, Lean and Sustainable Construction that can help to identify positive interactions of technology and management to attain the goal of sustainability. Through Figures 1 and 2 at a very preliminary conceptual level the integrated framework for BIM, Lean Construction and Sustainable Construction can be illustrated. Figure 1 shows the stages or phases in the integration of these three approaches. Phase 1 shows the X, Y, and Z axes representing S (Sustainable Construction), B (BIM) and L (Lean Construction) respectively in isolation. Phase 2 shows the integration into pairs such as the B/S, S/L and B/L plane which suggests a 3 dimensional cube. Phase 3 represents the full integration of BIM, Lean Construction and Sustainable Construction in a 3D cube. The core idea of this integration is to find out BIM and Lean principles that support certain Sustainable principles. As an example reduced material waste (Pulaski, 2006), computer controlled fabrication (Sacks et al., 2010), reduce variability (Sacks et al., 2010) are subsequently representing Sustainable Construction, BIM and Lean Construction principles. Where reduced material waste (S) is supported by both computer controlled fabrication (B), and reduced variability (L) which creates a Sustainable construction process named prefabrication (Luo et al., 2005). The colour coding in the cube represents the supportive relationship as explained in the example.

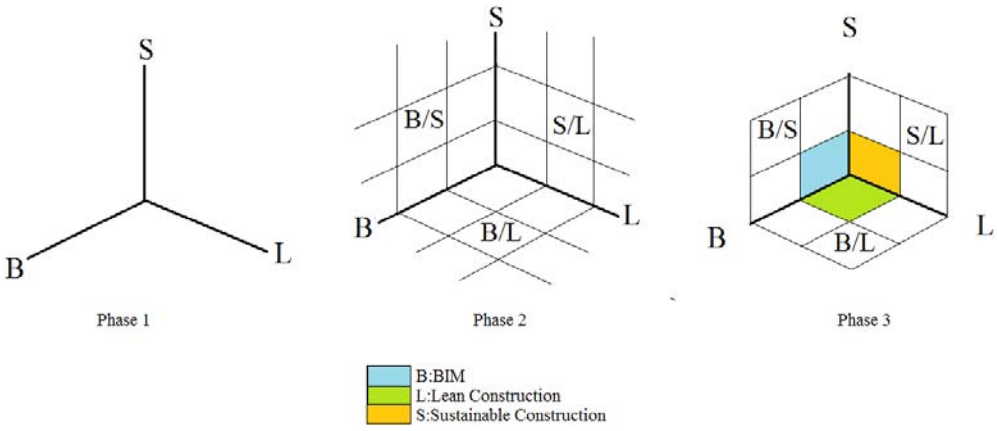

Figure 1: Integrated framework of BIM, Lean Const. and Sustainable Construction

Figure 2 illustrates how the mutual relationship among BIM, Lean and Sustainable Construction may be integrated together to enhance all the possible Sustainable features in AEC projects. This "3D model integration" may work in the different phases of the project. Figure 2 also shows that different "integration principles" could be applied at different stages of a AEC project. The "3D model integration" could work as a guideline to the whole life cycle of a project to rectify different Sustainable measures and barriers through the supportive synergy of these three approaches.

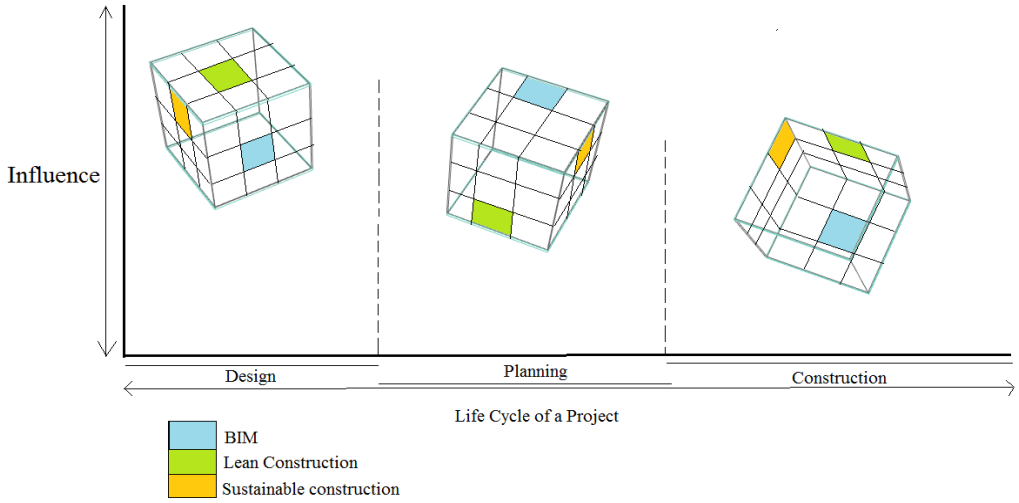

Figure 2: BIM, Lean Construction and Sustainable Construction integration implementation in different project phase

CONCLUSIONS

BIM, Lean Construction and Sustainable Construction are instrumental for both academics and practitioners in the AEC industry. These three

approaches or drivers are currently implemented in different projects in a discrete manner. However it has been identified that BIM and Lean have a vital role in Sustainable projects and underlying benefits are beneath their integral application. This integral approach or "3D model integration" has not yet revealed the maximum Sustainable value for the AEC industry. Therefore, the conceptual framework proposed in this paper may be a pathway to achieve Sustainability in construction through integrating BIM/Lean/ Sustainability. Hence a collaborative approach from academics and industry is a dire need to explore different dimension of this integrated approach.

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