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# *Interaction between Lean Construction and BIM*

How effectiveness in production can be improved if lean and BIM are combined in the design phase
A literature review

**Allan Fred Onyango**

ROYAL INSTITUTE OF TECHNOLOGY
DEPARTMENT OF REAL ESTATE AND CONSTRUCTION MANAGEMENT

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| Author: | Allan Fred Onyango |
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## Abstract

The Construction industry has had a relatively low increase in the efficiency rates over the recent years. Two developments of Lean construction and Building Information Modelling(BIM) have been introduced that have each shown improvements in the efficiency rates in construction. These two individual concepts of Lean and BIM have been applied each independent of the other and because of their similarities and overlapping benefits, it is thought that them being applied together improves the efficiency in a greater way than them being applied individually. This study looks at the synergy that is possible due to the overlapping benefits in applying Lean Construction and BIM. The study is a Literature review aimed at understanding Lean and BIM and their overlaps. The Literature looks at past research studies that have investigated this area. The clear look at these studies shows that when the two concepts are combined, then that collaboration leads to a more integrated process in construction that in turn yields higher efficiency rates.

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## Sammanfattning

Byggindustrin har haft en relativt låg ökning i effektivitetstalen de senaste åren. Utvecklingen inom två nya områden, Lean Construction och Building Information Modelling (BIM), där man kunnat visa ökad effektivitet genom båda åtgärder. De två begreppen Lean Construction och BIM har introducerats oberoende av varandra på grund av deras likheter och överlappande fördelar men det är vid användningen av båda åtgärder samtidigt som den bästa effekten har kunnat visas i motsats mot om varje åtgärd hade använts separat. Denna studie undersöker synergieffekterna som är möjliga genom överlappande fördelar vid användandet av Lean Construction och BIM. Det är en litteraturstudie som syftar till att förstå Lean och BIM och deras överlappning. Litteraturen tittar på tidigare forskning som har undersökt detta område. En noggrann betraktelse av dessa studier visar att när de två åtgärderna kombineras leder det till en mer integrerad byggprocess som i sin tur ger högre effektivitetstal.

## Common terms used

**BIM**: Building Information Modelling. Refers to the word as a verb that refers to the process of the actors utilizing computer software to develop intelligent objects and models that are a representation of the desired solution.

**Lean Construction**: Techniques that have been developed overtime and applied to construction based on the lean principles.

**Synergy**: the interaction due to combined use of two concepts that when combined produce a greater effectiveness than would be possible when either is applied individually.

# Contents

# Introduction

The construction industry is one of the major contributors to GDP of the economy. In a report by Eurostat (2015), the construction industry contributed to 5.7% to the GDP of the Euro Area in 2013. It was among the top ten contributors to GDP in Europe. In Sweden, the contribution the construction industry made to the GDP in 2013 was 5.4% (Eurostat, 2015). However, a report by Mckinsey Global Institute (2006) shows that there has been a record of relatively low growth rate in the construction sector as compared other economic sectors. The construction industry did not record significant improvement in productivity in the recent years. This acts as also an indication on low improvement of efficiency of the construction industry in the recent years.

Over the recent past, a number of developments have been introduced in construction industry with the main aim of improving the efficiency in projects. Two major developments include; the use computer information technology in the form of CAD systems to design building drawings that later evolved to Building Information Modelling (BIM) (Eastman, et al., 2011). The other concept developed is the use of lean construction principles that are founded from the practices and philosophies that were applied in the Japanese automobile industry, Toyota (Womack, et al., 1990).

BIM involves process in which digital models are made containing intelligent 3D objects, these intelligent objects contain the information of properties that the items it represents. The models are used to facilitate the construction in the production stage (Eastman, et al., 2011). This enables the actors in the design process have a clear understanding of the project through visualization. Therefore, with a clear understanding of the client's requirements, the best solution can be made to fit well what is required. In the BIM process software packages are used to for drafting purposes (Sacks, et al, 2010). A number of different packages have been developed and some of the main ones include; Autodesk Revit and Archicad. These packages are utilised in the design stage to draft the models. In cases where BIM is implemented suitably in projects results show better quality constructions made at lower costs and shorter durations used (Sacks, et al, 2010)

Lean principles where formulated from the Japanese automobile industry (Womack, et al., 1990). These underlying principles in lean, referred to as the Toyota Production System (TPS), aim to reduce wastages, achieve clients' expected value and lead to continuous improvement in the deliverables in projects (Sacks, et al, 2010). From the lean principles an adaptation was developed for the construction industry. Since it was based on the original lean principles, the objectives were therefore built from those very lean principles. These objectives were to meet the requirements that were set by the client with minimal wastage in the effort, materials and time (Howell, 1999). With time of this being practiced, various techniques like Last planner system and concurrent engineering were developed and these tested and proved an efficient was of capturing the lean approach (Egan, 1998).

These two developments of Lean construction and BIM have mostly been applied separately whereby application of one could be done without the other. Both developments have contributed positively to benefit the construction industry. With the progress that has been made through the use of both, studies have emerged about understanding how the two can be used in a joined complimentary manner instead of independently. In a study by Sacks et al., (2009) the works explore widely in construction the different interactions that exist between BIM and Lean. The study states that a synergy could be achieved if they are intentionally applied together. The authors identify 56 different interactions between lean and BIM, 48 of which are considered constructive with backing empirical evidence from works of other scholars. The study by Sacks, et al.(2010) does not go in detail but rather gives a general framework of these interactions.

In the design phase, BIM and Lean Construction show clear intersections in the objectives that they are meant to achieve and the synergy between the two that could be harnessed. For example, both BIM and Lean Construction processes focus greatly on delivering the client's requirements. In BIM, the actors in the early stages design what will be the final delivered solution while in Lean Construction, one of the objectives is to achieve client's final expected value (Koskela, et al., 2002). These values are understood from the start to ensure that they are achieved upon completion. Also another clear relation is the use of BIM software like Solibri Model Checker to detect clashes early on in design to ensure there is no wastages later in production. This act of reducing wastage is one of the principles in Lean Construction (Koskela, et al., 2002).

In light of these initial studies and insights, an area of interest is developed in which BIM and Lean Construction are studied in theory to gain a better theoretical understanding of how the two can be applied together to achieve the expected synergy. In understanding this in theory, then these concepts can thereafter be applied practically on projects.

**Aim**

The aim of this research paper is to study the interaction between Lean construction and BIM focusing mainly on the design phase in construction and investigate how they can be implemented in a way that leads to increase in efficiency in projects.

The rest of this paper is arranged in order following these main heading; research objectives, methodology, scope, literature review, findings, analysis and conclusion.

**Research Question and Objectives**

The aim of the paper leads to the research question*; how effectiveness in production can be improved when Lean Construction and BIM are combined from the design phase.*

BIM is utilized from the design phase while the Lean Construction is at the production phase. However, in order for the maximum synergy to be harnessed, Lean Construction must be well planned and integrated from the design phase into BIM.

This study therefore explores these interactions in the design stage in order to gain a theoretical understanding of them and then suggest ways in which these synergies can be successfully implemented in practice.

The design phase is thus taken to involve the use of BIM technology as a tool that will be used jointly with Lean Construction principles.

In order to answer the research question, the following objectives are set to facilitate the study:

- Investigate lean production principles and how they are applied in construction
- Investigate BIM, its implementation and functions in design stage.
- Study how the lean principles in construction and BIM functionalities intersect in the design stage.
- Suggest ways in which synergies between lean construction and BIM can be successfully implemented.

## Research Methodology

The research carried out is a deductive study. This is by reviewing the previous studies carried out by different scholars related to construction that include Lean Construction or BIM and in some cases both Lean construction and BIM where investigated in the same study.
The studies are from different resources that include; peer reviewed journals, conference proceedings, past written master's thesis, reports and textbooks. These sources where selected on the basis of two main criteria, the first being that they contain the relevant information in study area. The study areas being BIM and Lean construction.
The second criteria chosen was that the studies where from highly ranked sources. The term highly ranked sources represent the sources that were commonly cited in various sources.

The sources selected had three main categories; one that focused on BIM, another focused on Lean construction and the third focused on both BIM and Lean in the same study. At least 10 studies from each category were selected.
The sources that studied BIM and Lean construction independently were used to form the literature review section of the research while the sources that contained a study of both BIM and Lean in the same paper constitute the findings sections of the research.

The analysis and discussion made was derived from the understanding and integration of the knowledge assimilated from the read past studies. With that understanding, informed recommendations were extrapolated from these studies to suggest how these intersections can be implemented in a successful way during production to achieve the synergy between the BIM and Lean construction.

## Scope and Limitations

The research is limited to the use of BIM design phase in projects and evaluating how Lean Construction principles interact with BIM in this stage and thus be planned.

A limitation of this study is that it will only look at previous studies by various authors and empirics and no actual site works investigated.

The study is also limited by short time meaning thus a limited number of previous studies are looked at.

# Literature Review

Understanding both Lean Construction and BIM from the foundation principles is essential to then investigate the possible interactions between the two in the design phase. A look at the foundation of Lean Construction and BIM study are discussed in this chapter.

## Lean Construction

### Origin of Lean Principles

The origins of the lean concept emerge from the studies from Japanese automobile industry called Toyota which study was a critic to the American auto industry that utilised a system of mass production (Womack, et al., 1990). As mass production focused largely on quantity, this approach exhibited defects, high inventories and low variety. In mass production, the work was done by unskilled or semiskilled workers making products as had been designed. The flow of the system continued even when there was a possibility of defects carried on since these would be later rectified in the reworks sector. Therefore wastage was high arising due to defected pieces discarded, time to do reworks and effort spent on non-value adding tasks (Womack, et al., 1990). Other problems that were noted to be in the mass production included; lack of coordination and communication between different divisions, quality issues only realized at the end of production, impossible designs or design changes that necessitated reworks.

From this analysis a better way to do production was derived and introduced called the Toyota Production System (TPS). This system offered an optimal method of delivering value from supplier to consumer (Womack, et al., 1990).

Therefore, to improve the system of mass production, TPS focused on these main objectives; Maintaining efficiency, Better Quality through continuous improvements, Creating a flow of system and value to consumer (Womack, et al., 1990). In order to do so, waste reduction was also a main focus in TPS. When a defect was detected, production stopped, and this defect was worked on immediately without passing on a defected product to the next stage. This ruled out a need for reworks. With time it became easier to spot defects early in the system, hence the system was improved in way that led to fewer possibilities of defects arising with time (Womack, et al., 1990).

To coordinate the projects day to day flow of the supply logistics, a *kanban* system was developed (Womack, et al., 1990). This system uses a trigger that sends a signal to the supplier to deliver to the production site the required materials. This cut out the need for inventories since materials were delivered in the precise amounts and specification when needed to be used (pull system). The overall impact of TPS lead to a value addition in every stage whereby all non-value adding tasks were eliminated (Womack, et al., 1990).

The emergence of TPS led to production having two distinct forms thus mass production and lean production. With the mass production focussing speed and efficiency to produce a large number of products while lean focuses on producing unique product to conform to the specific requirements of the client without need of inventory and minimal wastages (Howell, 2000).

A definition of Lean production was given by (Koskela, et al., 2002) as : a way to design production systems to minimize waste of materials, time and effort in order to generate the maximum possible amount of value.

**Lean Principles**

As the success of Lean production was evident in the manufacturing industry (Howell, 1999), different scholars set to clearly define the principles which underlay in Lean production, so that with that understanding, it can be applied well in the areas implemented.

The 11 principles of lean as stated by Koskela (1992) included the following listed:

- Limitation of non-value activities
- Deliverable achieved as per client's requirements
- Reduced variability
- Reduced cycle times
- Simplify any complex bits yet maintaining quality
- Flexibility in deliverables
- Transparent process
- Maintain control through whole process
- Continuous improvement made in the process
- Balance flow improvement with conversion improvement
- Benchmark

The principles stated by Koskela (1992), gave a wide comprehensive list view of the different principles of Lean that have been applied and investigated over time. In a study by Aziz & Hafez (2013), the lean principles were summarized to a smaller list than that of Koskela (1992). This list was meant to capture the fundamental issues of Lean.

Five fundamental principles of lean stated by Aziz & Hafez (2013);

- **Specify value:** This is understanding client's requirements clearly and ensuring that the specifications are well illustrated. Since the client defines the needs, when this need is met, then value is delivered to the client.
- **Value stream:** this involves different tasks break down, material break down to the lowest level. In doing this the detail of the process is seen and therefore the value from each small detail is determined. This is essential since all non-value adding tasks can be removed since they do not contribute to the value stream.
- **Flow:** This entails the movement of resources both materials and human. These resources are moved in a way that they are available when and where needed. This is availability of different teams at the optimum times and working of the supply logistics well.

- **Pull:** there is no need for have buffers and inventory in the system. The materials are only made available at the time of need and in the quantity and specification needed. When the need for specific resource in the system, a signal is sent to the supplier to deliver the needed resource.
- **Perfection:** Continuous improvements to keep the system getting better. Aiming for perfection leads to the production system to keep stretching and achieve results that even were previously thought impossible.

### Application of Lean in Construction

These principles being understood well were extended to be applied to other industries for example healthcare, leadership management and construction. According (Sui Pheng, 2011), the Lean approach can also be referred to as the Toyota way model. The growth of the Toyota motor cooperation has inspired many organizations that have gone on to replicate it's the strategies and have benefitted from them with higher levels of productivity (Sui Pheng, 2011). This original idea of Lean from the manufacturing industry was adapted, modified and improved in the different areas of application (Hines, et al., 2004). The idea of lean production arose due the success that was achieved in the manufacturing industry and from this the principles formed that are then applied to construction (Koskela, et al., 2002).

The construction industry did not adopt the lean approach quickly due to the fact that attitude was that construction in itself was taken to be different from manufacturing (Howell, 1999). Manufacturing utilizes the concept of mass production while in construction, each project is independent and unique, with various teams working on a specific objective to completion and the level of uncertainty being high at the start, reducing with progress. In cases where the objectives are not met, the work is redone while in manufacturing, the work can be discarded.

Fernandez (2003), through an in-depth study of Lean principles investigated ways in which Lean could be adapted into the specific character of the construction industry. The differences that existed between the manufacturing industry and construction industry were evident despite the fact that some similarities were also present. Some products of the manufacturing industry where used in construction and also there was a similarity in the two processes. Due to these similarities, a foundation could therefore be laid to launch on how Lean principles can be applied into the construction industry (Fernandez, 2003). Construction involves projects that are carried out usually on site based on contract relationship unlike manufacturing (Brockmann & Birkholz, 2006) however this trend in construction is bound to change with the gap between manufacturing and construction getting smaller (Ashford, 2002). This is can be illustrated by the gradual increase of techniques like off-site production and prefabrication (Sanvido, 1988) This change has laid a bigger platform for the manufacturing approach to be imported to construction and therefore application of lean thinking into construction also. The use of lean thinking into construction leads to an increase in customer satisfaction that derives from the fact that in Lean, the thinking is concentrated in ways to improve value and efficiency of the operations (Latham, 1994).

With the application through time, it has been evident that Lean Construction provides more effective results than traditional forms of construction and thus can be seen as not only as an alternative to traditional construction but as a replacement to the traditional ways things are done (Koskela, et al., 2002). The rest of this section looks specifically at some of the ways Lean Construction has been applied.

Lean Construction methods have been introduced whereby the principles are used to refine the construction process so that the client's requirements are achieved in more efficient ways.

According to Oakland (2006), the Lean Construction process can be understood from the view point of the client. What the client wants and how those needs can be satisfied. They emphasize that for a construction process to be lean, it needs to be done with no wastage of any resource to ensure maximum value addition is achieved. Only items which are valuable to the client are delivered and all the steps in the value adding process are closely evaluated. The authors however admit that there exists no such thing as a perfectly lean process but they believe it could one day be achieved. The focus of lean thinking and production, according to the study, is focused on the customers' needs, creating added value and eliminating waste. This same issue was explained by Koskela,et al (2010) as the aim is to ensure that the clients requirements, that are made at the intiation stage of the project have all been achieved at the project delivery stage. The clients requirements include the specific goals the client would want to see delivered plus the intended use of the product fufilled. These requirements are achieved through the supplier understanding clearly the clients requirements then having the necessary product design, order delivery and production to meet the clients requirements thus provide value to the client Koskela (2000).

In regards to time wastages in construction projects different studies capture this. A study by Ashworth (2006) shows Lean Construction aim to removing all the non-value adding processes in the system. While looking at a system where the resource time is scarce, it is of the essence to do whatever is possible just to remove all time wastages. For any activity in the chain which adds no value can at this point be considered as a time wasting activity. For a construction company to achieve cost reductions without affecting quality, such a company must consider ways to reduce the amount of time spent on site. Kalsaas (2010) states the different sources where time wastages occur which are;

- Overproduction; where more than can be utilized or required is produced.
- Waiting; when work stops because required resource is not available at the moment.
- Defects; leads to requiring reworks to be done.
- Inappropriate processing; use of inadequate techniques or lack of clarity.
- excessive transportation.
- unnecessary motion; for example, from placement of material far away from where they will finally be applied.
- unnecessary inventory; this occupies space with extra handling needed that takes time.

Ashworth (2006) states that elimination of such time wasting activities should start with the early design process all through construction to the point of handover of the project. The study also elucidates more on the time wasted on correcting defects. The study suggests that works should be performed right the first time because the amount of time spent in correcting defects is not aimed at increasing profitability but rather it leads to an increase in the costs Ashworth (2006). The lean principles in construction are applied in a way that tasks are assigned the required resources. Therefor no under or over utilization of resources is done and the availability of these resources are Just In Time (Howell, 2000) .

Another principle in lean emphasizes on the production system flow of the on ground progress of works to ensure that there is control and continuous improvement in the process (Sacks, et al., 2010). Different techniques have been applied to this for example looking to ensure simplification of the systems, using parallel processing whereby more than one task can be carried out simultaneously and use of reliable technology. These methodologies of Lean Construction that can be used to apply the Lean thinking to construction include; Just in time (JIT) approach, concurrent engineering and Last Planner System(LPS) (Koskela, et al., 2002). These methods mentioned can all achieve ways in which Lean approach is applied in the construction process which leads to reduction in wastage and therefore cost on projects.

Just in Time (JIT) approach looks at the ensuring availability of resources on construction sites at the right time for application or usage, not arriving prior to the required time or later. In a study by Pheng (2001), it was shown that precast concrete delivery on site in Singapore was critical in the saving of time on a project and thus should be implemented well in the planning of the construction process. JIT focuses on the removal of wait times in construction (Koskela, 2000).

Concurrent engineering is applied in a way so parallel tasks happen with adequate communication between the teams (Koskela, et al., 2002). This seeks to shorten the cycle times of bringing a product to the market through a thorough understanding of the client's needs, forming capable teams that can carry out parallel design of the required assignment which is delivered (Jarvis, 1999). Working in l reduces the total time needed in the construction process which enables the goal to be achieved within the time deadline.

Another application of Lean Construction is use of the Kanban system. This as in the principles of lean is meant to maintain a flow in construction with no need of inventory (Koskela, et al., 2002). In this system, in order to get materials to site when needed from an away location, the need is transmitted through a signal. This is therefore in cases where the material is made off site and therefor prefabricated and then delivered to site.

One of the major applications of lean that has been developed into the construction industry is the Last Planner System (LPS) which is used as application of lean principles to construction. This system is characterised to form a well coordination organization of the flow of tasks throughout the whole process all before the actually work starts. This also spells out how the system will be controlled in case of distraction in the flow (Ren, 2012). When lean principles are applied to construction like Last planner System, there is minimization of wastage in time on the construction and improved efficiency in construction (Issa, 2013).

LPS has the following characteristics that form the nature of the system (Koskela, et al., 2002) ;

- Reliability of production; with day to day production leading to an expected product to be delivered.
- Collaborative process; between different teams and disciplines part of the project.
- Pull process: so that right actors get right information at right time, thus when they are ready to be done, like ceilings done after the necessary M&E works have been completed.
- Work backwards from the target: clearly understanding the target from the start being essential.
- Tasks Made Ready(TMR): when the teams can start the task without any constraint.
- Plan Percent Complete (PPC): this shows how many tasks were completed as planned, to be able to track progress on what was planned.
- Root Cause Analysis(RCA): to check what caused the deviation from what had been planned, to ensure that we eliminate root cause so that this is not repeated.
- Schedule: At three different levels that is master schedule, phase schedule and look ahead plan (weekly plan).

The Last Planner name denotes that the person on site that is in charge of the tasks at hand for example that the foreman has a weekly schedule in place.

## BIM

### Defining what BIM involves

In the different developments in the construction industry, BIM has shown to be a key development to take the industry forward. BIM thus ensures a continual process in design and production, by ensuring that communication is passed on well from the designers to the constructors. This creates an integrated process in construction (Eastman, et al., 2011).

The definition of BIM by the professionals has a wide array of views, most of which are derived from the perspectives of the actor defining it. A contractor defines BIM as a process, designers define it as intelligent 3D models, while most other professionals define BIM as a visualization tool in construction (Barlish, 2012).

With the different views the industry has about BIM, the need to have a standard by which different actors can agree upon led to the formation of national standards for example the National BIM Standard (NBIMS), (Eastman, et al, 2011).

The National BIM standard (NBIMS) categorizes BIM in three ways;

- Product
- IT enabled collaborative process,
- Facility life cycle management requirement

For the purposes of this paper, the definition of BIM that will be taken is it being a process in which digital models are created in the design phase which are used and may be modified when needed in the construction and operation phases of construction.

The purpose of looking at BIM as a process in this paper is to acknowledge the fact that as a process it involves different sets of actors, the professionals, and these actors carry out different tasks which all contribute to the final deliverable, that are the intelligent 3D models. It is also critical to point out that the BIM process continues even further in to the next stages, however the scope of this paper to look at only the design phase.

In BIM, the deliverable are intelligent objects and not just 3D models. These intelligent objects also contain the required information about the object itself above visualization aid it provides. They have parametric intelligence and can be moved in regards to any changes that affect the objects (Eastman, et al., 2011).

Traditional methods have in the past been used in construction. These methods involved the use of 2D drawings that were drawn by hand on paper. This however evolved from the CAD software that still utilized 2D drawings that further evolved to 3D drawings and now currently BIM which utilizes 3D (Lindblad, 2013).

The evolution of how design has been evolving trough the different levels is well illustrated by the maturity level diagram (Bew & Richards, 2008)

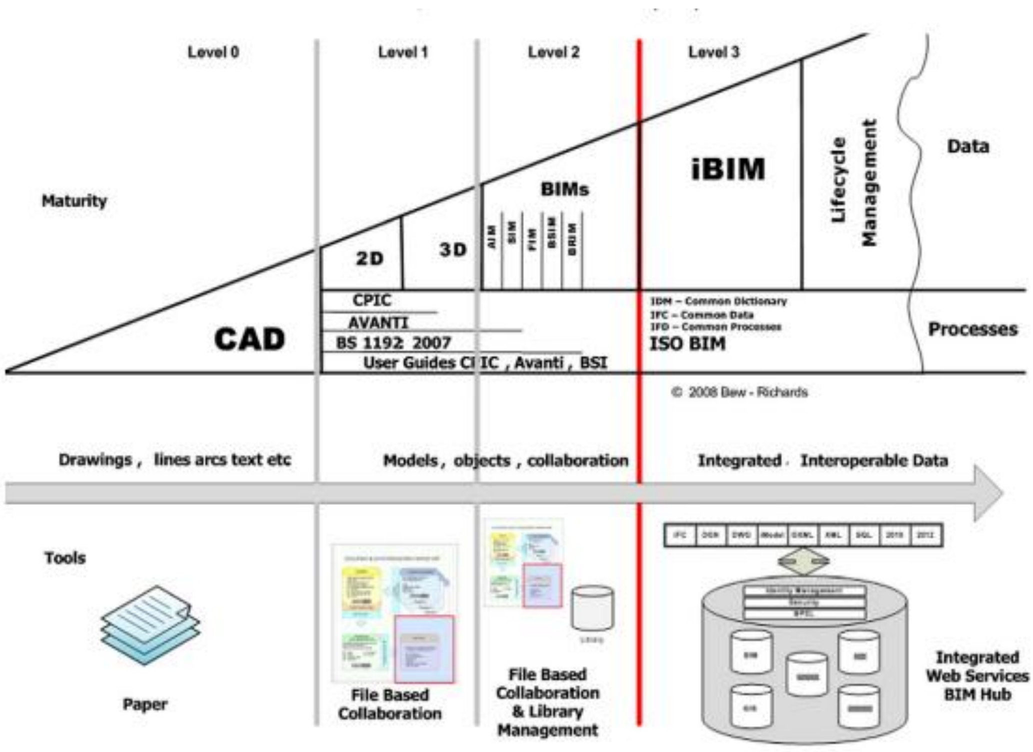


Figure 1: The different levels of BIM maturity (Bew & Richards, 2008)

The different levels of BIM maturity are explained as;

- Level 0; Traditional method that involved the use of papers.
- Level 1; with the introduction of the computer age, the construction drawings were done on Computer Aided Programs(CAD) like AutoCAD first in 2D then later in 2D.
- Level 2; which is the current level that involves BIM.
- Level 3; which is the future of BIM, that will be more integrated thus referred to as iBIM.

BIM shows the potential capacity to achieve more especially when looked at the areas of scheduling, sustainability and facility management (Eastman, et al., 2011). BIM has also evolved in way of dimensions. The evolution in dimensions to have 4D, 5D and 6D BIM are related to the added information that can be placed in the models and intelligent objects (O'Keeffe, 2013).

These dimensions are sometimes classified as follows;

- 4D BIM; that includes programming and scheduling information (Sulankivi, et al., 2010)
- 5D BIM ; that includes Quantity Schedules and Costing Information (Smith, 2014)
- 6D BIM; that includes Facilities and Asset Management (O'Keeffe, 2013)

**BIM implementation in design and challenges**

To implement BIM, there must be change in the way of practice in the works. This requires a high level of collaboration and integration that must be attained for it to be successful (Gu,2010) In order to adopt BIM into projects and firms that have not originally been using BIM as a method of operation, there has to be structural changes which may necessitate the creation of new roles for example BIM manger. Creation of a role of BIM manager ensures that all the different aspects of the adoption are taken care of and this may include the legal issues, cultural issues and procurement options (Porwal & Hewage, 2013). Most of the firms find it more convenient to source in-house rather than rely on consultants for the BIM works (Majcherek, 2013). However, when the in-house option is chosen then in that case the workers are not familiar with the skills needed, it may take some time to train them.

Usually the client is the main determinant on initiating the use of BIM on projects (Porwal & Hewage, 2013). If BIM is made obligatory for projects, this would limit the possible firms that may take part in the competition. Therefore, it is up to the clients to set a requirement to use BIM to ensure that more firms adopt it not to miss out on possible projects (Porwal & Hewage, 2013).

For example, in UK where all public construction projects are now required to use BIM at a level two maturity level (Mcgough, 2013). As has been stated, BIM adoption is mainly motivated from the side of the client or the architect, however if BIM was adopted mainly due to the request of the main contractor, then the advantages of BIM would be more defined in areas of production like health and safety, day to day tasks, site communication and planning (Arayici, et al., 2012).

In the adoption of BIM in to projects in a company there must be a strategy that involves the interaction between the actors and the process. Thus the actors having the right attitude and required training to acquire relevant skills and management strategy will be able to minimize and reduce all that hinders that adoption (Arayici, et al., 2011). Having a more strategic planning process in the design phase is key in ensuring that the production phase is carried out with minimal mistakes and thus less wastages (Hjalmarsson & Höier, 2014).

When BIM is introduced, there are different actors that take part in contributing to the design phase. Each professional specializes in the respective parts like the structural engineer working on the structure and the mechanical engineer working on the ventilation. After the different actors have independently designed the respective parts, they are brought together into one model (Eastman, et al., 2011) Usually the works go back and forth as the different actors all work to form the best chosen alternative and in some case also correct any clashes or errors that may have been made (Eastman, et al., 2011).

The challenges that are in the implementation of BIM are both technical and non-technical. The technical include absence of industry standards, whereby exchange of information between different software packages is either not possible or information is lost. The way data is exchanged between different software systems may be hindered by issues of incompatibility. This can serve to be a frustration which is being tackled by introduction of open BIM standards like the Industry Foundation Class (IFC). The open BIM versions are not without fault and still being improved especially to work with more detailed parameters (Porwal & Hewage, 2013). Another challenge is the security in the process and how in BIM rights will be kept by only those who are authorized to access the information and thus no distortion of the information set by other unauthorized parties (Gu, 2010).

Due to the different procurement methods available, a gap is created in the ones in which the contractor is not part of the design phase. The use of BIM in this case will not achieve the full potential (Porwal & Hewage, 2013).

The new approach of BIM and use of digital information also faces a challenge of the attitudes of the actors that are familiar with the traditional methods of work, and thus face a hurdle in having to learn new approach (Hjalmarsson & Höier, 2014).

A major challenge in the BIM implementation relates mainly to software and hardware incompatibilities, which can be worked up on by necessary trainings and planning by management to be organized in efficient ways. A way to work around the software is expected. And investment is needed to be done (Bryde, et al., 2013).

The non-technical bit includes the adoption of new roles and responsibilities that are in place to handle this new paradigm for example design manager (Gu, 2010).

In implementation of BIM by architectural firms, despite the studies that have been carried out to show the profitability of BIM, the affordability stands in the way in the implementation. Leaving some of the architectural firms  in Sweden to only consider use of BIM when the client explicitly requires it be used (Majcherek, 2013).

**BIM functions**

When BIM is implemented in projects, one of the advantages is that it provides a platform for increased efficiency in projects (Arayici, et al., 2012). Looking into the main functionalities of BIM, its implementation results into delivering both tangible and intangible properties (Turk, et al., 1994)

BIM process leads to production of visualizations in form of 3D models that are representations of the possible design solution. This is critical to ensure that the entire team has a clear understanding in the solution design and that those without technical background but still part of the project team especially the client have a clear understanding (Sacks, et al., 2010) Through this function, the different actors in the project can therefore understand and communicate with each other in a clear way with less chances of misunderstandings (Hjalmarsson & Höier, 2014).

Another important functonality of BIM is the possiility to quickly generate various design alternatives that can then be compared to each other to pick the best alternative. This also works in a way that in case a change needs to be made in the design, it can be changed quickly and this change is adapted to all the different aspects affected of the model, like the cost estimation, material count and scheduling and also to all the affected paramaters (Sacks, et al., 2009).

Furthermore with scarse energy resources, BIM also functions to enable building performance analysis to be done. Through these analysis which is done in the early stages of design, decisions can then be made to ensure that the building achieves sustainabilty objectives producing an optimized sustainable building design (Azhar, et al., 2009) Another scarse resource is time. When BIM is adopted from the start of construction projects and all the stakeholders take part, a positive benefit is realized of short construction cycle times in projects (Bryde, et al., 2013)

MEP covers a large percentage of value in projects, in some projects even up to 50% of the costs, therefore it is vital to have this coordinated well which can be achieved with BIM, to overcome the complexity and low operational space available. BIM is used as a tool to manage the coordination well (Khanzode, et al., 2007). With the increased use of BIM, improvements are expected to be seen in team collaboration, lowering of costs in construction, less time wastages, better stakeholder relationships (Azhar, 2011). _BIM benefits also include better collaboration between consultants and actors (Hjalmarsson & Höier, 2014). BIM facilitates participation of all the actors in early design phase to ensure better collaboration and an integrated project delivery (Bryde, et al., 2013).

BIM also facilitates that there is better communication between the different stakeholders and is essential in relying information where the construction sites are in remote locations (Arayici, et al., 2012). With BIM all the information is available for the required team members. Also any information about changes that may be made are available. This also brings down the possibility of reworks to be needed out of misinformation (Khanzode, et al., 2007). When Using 3D BIM, it is possible to have 2D drawings automatically produced and these can be used to provide relevant information to the required actors (Hjalmarsson & Höier, 2014).

Using BIM, the 3D models from different disciplines designed to be constructed can be checked to detect any clashes which can then be corrected in the respective discipline and re checked until the model is free from clashes (Khanzode, et al., 2007). For example ,in project of Moreton Bay Rail link in Australia and the Stockholm bypass case studies, the major benefit of the use of BIM in these projects as noticed by the project managers and architects in the respective projects was the fact that clash detections could be done and controlled for in the design stage (Hjalmarsson & Höier, 2014).

With BIM the clashes can be detected due the fact that different professionals working on the design team are able to share knowledge and information and through their expertise and the use of BIM software can they detect errors and clashes early. 80% less errors were recorded in the cases when BIM was applied (Majcherek, 2013).

BIM can be used in cost estimation. This is possible by automatically extracting the material quantities form the models to which quantities then are applied the market rates of each material to come up with a sum. An example includes the Autodesk quantity Take off which when in project allows the user a single click to extract all the needed quantities from the models (Azhar, 2011). The aspect of cost is the most positive affected aspect in the adoption of BIM (Bryde, et al., 2013)

# Findings

The studies on Lean Construction and BIM in the previous chapter have been carried out by different researchers having focused mainly on one of either of the concepts to increase the understanding of them. However, as research in these concepts has gone in detail and more knowledge is being understood of the two concepts, the interaction with lean and BIM has been recognized and therefore more work is being done to understand this more in theory.

**Lean construction and BIM interaction framework**

Since the idea of combining BIM and Lean Construction is a recent development, a number of researchers have carried out studies to understand these interactions better and also form possible hypothesis that will enable the concept to be developed further. This section deals with these studies:

An essential study in this is titled *Interaction of Lean and Building Information Modelling* (Sacks, et al., 2010). In this study, the different interactions that exist between BIM and lean are explored. Although BIM and lean have initially been applied independent of each other in projects, the study focused on identifying the synergy that can be achieved if they are used together. The study therefore comprises of a methodology whereby previous works of different authors are thoroughly examined to identify these interactions. Through the use of a matrix framework of interactions, the authors identify 56 different interactions between Lean and BIM, 48 of which are considered constructive with empirical evidence backing this. Through the understanding of construction concepts together with companies adopting lean and BIM, albeit in small steps, the authors suggest that it will result to even bigger increments in the productivity rate. The study however does not look to study in detail a specific single interaction in the framework but rather gives a big picture of the various possible interactions.

From Sacks (2010) study, the interactions between lean and BIM that are involved in the design phase found are three. The first one is how multiple team actors are able to modify and edit different design alternatives across the different software packages that may include Autodesk software packages, solibri, navisworks etc. This together with the way changes can easily be made to all aspects in the model shows the functionality of BIM in the rapid generation of design alternatives and from lean principles it shows how the design of the production system and flow of value is made (Eastman, et al., 2008)

The second interaction from the Sacks (2010) study is that the multiple users are able to work in parallel with the same model that means that the work load is shared according to the speciality of the different teams. In such a way it is possible to have the high quality since each part for example the structural and architectural designs can be carried out with reference to each other while ensuring that the two plans fit well together, and therefore not design based on only aesthetics and not consider the structural integrity needed.

The third interaction from the Sacks (2010) study shows that since BIM provides visualization of the project and the projection flow, the sequences of the tasks on the construction site can therefore be simulated to identify and potential resource conflicts and clashes in the day to day production. With Lean Construction having an objective to create flow of the tasks, this is complimented by that while using BIM, resources can be allocated in a way that is planned for a flow to keep going without resources being over or under used.

The above study by Sacks (2010), laid the foundation for other studies to further investigate the concept of combining BIM and Lean construction by showing more of these interactions and also other studies forming hypothesis:

With the advancements made through BIM, its implementation and application, it has shown that it can be used in aiding the achievement of Lean construction objectives. The objectives that Lean Construction has like waste elimination, increase in value to client and team collaboration. All of these objectives have been obtained when BIM is applied. In three case studies where only BIM and not Lean construction where applied, the results showed that some characteristics of Lean construction were evident in BIM application. The hypothesis is thereby formed that Lean construction and BIM should be conjoined and always applied as one. This hypothesis is from the view that when BIM is applied independent of Lean being applied in projects, the lessons learned enable the project to be able to apply Lean. Therefore, showing that BIM in itself may actually be redefined to be a lean process itself. One of the case studies looked at how the use of BIM lead to less variability in the scheduling. By the use of 4D, BIM schedules were made to look ahead and simulate possible causes of bottlenecks and collisions that may occur in the teams' coordination or logistics and prevent them before they happened. Another observation was the detection of clashes acted as a warning system that ensured that wastages were minimal (Gerber, et al., 2010).

When BIM application is used together with collaborative planning then the effectiveness in eliminating non value task is possible (Mattsson & Rodny, 2013).

BIM is used in its functions to eliminate wastage through having adequate clash detections and scheduling well, it also ensures that the design is clear to all the actors and enables a better collaboration between construction team members. Due to all this a hypothesis is formed that BIM is a tool to make the process Lean since through it a number of Lean Construction objectives are met (Ningappa, 2011).

In a study by Rischmoller, et al.( 2006), the focus was placed on how value generation can be improved in the design process of industrial projects using computeradvanced vizualization tools (CAVTs). The study shows that when production theory and lean principles were applied togethere with the information technology , the uncertainity throught the whole process was reduced which contributes to reduction in variability. This makes it easier for the clients requirements to be meet hence giving value from the supplier to client.

An article titled *Analysis framework for the interaction between lean construction and building information modelling* (Sacks, et al., 2009) had an aim to investigate how BIM supports changes in design and production brought about by lean. To describe more clearly, the study looked at what intrinsic values adoption of BIM brings to construction that ensures;

stable flow of production, lower wastages and value generation of deliverables (lean concepts). The methodology of the study was through carrying out extensive literature review on past studies to find the linkages that were necessary to the aim.

Through these linkages, a framework of analysis was created for assessing the interconnections of lean and BIM. This framework of analysis could be used as pattern of the interactions between new information technologies and the production systems they serve. With the framework developed by the authors, room for further and more detailed research is created.

Lean principles through promoting reduced variability to shorten waiting times. Also encouraging the concepts of Just-In-Time production and prefabrication Pheng (2001). These concepts are made easier to be applied by BIM, this also further emphasises the interaction between lean principles and BIM.

**Implementation of BIM and Lean Construction**

With the understanding of the combination of BIM and Lean Construction, the next logically step is to look at the way this can be Implemented into practice. Different scholars have studied the ways in which the two concepts can be merged and some studies also show the challenges.

In this study of the requirements for building information modeling based lean production management systems for construction (Sacks, et al., 2010). The construction process usually involves varying temporal teams that work with a set of different objectives assigned to each team. This leads to cases where construction sites are filled with different number of teams all working separately causing congestion and increased waiting times for the teams. With such a scenario painted'', it is reasonable to expect variations in production and delivery rates. With the use of BIM, the planning process in construction is aided through the ability to create visualizations of the deliverable. Different improvements have been made of BIM have been introduced to handle the actual production phase: these are named "4D" that includes scheduling and "5D" that incorporates cost. The authors however suggest that these additions have not explicitly dealt with the production planning and day to day production on construction sites. In order to form a better solution, the authors developed a system called *KanBIM* (involving Kanban style pull process flow and Andon alerts). This system incorporates the Last Planner System (LPS), a form of lean, to the BIM system. The system was analyzed through set up workshops and tested by different companies that gave feedback through use of questionnaires. The feedback showed that this concept provided both visualization capabilities in addition to control in the production process to deliver at stable rates. This shows the complexity of the interaction between lean and BIM in a well thought of system.

In a study, *Technology adoption in the BIM implementation for lean architectural practice* (Arayici, et al., 2011), it shows that the construction industry has in the recent past has been introduced to BIM which has been essential in improving the productivity and efficiency rates in the industry. However, despite all the success that has been achieved, there still lies a deficiency in having an implementation system of BIM to projects. It can be said that not all the advantages of BIM have been harnessed to gain a global competitive edge. These advantages may include increase in productivity, efficiency, quality and achieving environmentally sustainable targets. The authors in this study look at interactions between people and given system processes to investigate the guidelines of how BIM can be implemented in collaboration with lean architectural practice. The methodology was carried out by having a knowledge partnership transfer project between the University of Salford and the John McCall Architects based in Liverpool. Both qualitative and quantitative methods were used to analyze the socio-technical and socio-cultural environments with regards to implementation of BIM with lean principles. This results showed that when BIM was designed with elimination of wastes and value generation (lean principles) in mind, efficiency was best achieved with a bottom to top system of implementation.

BIM and Lean Construction have been utilized at different companies each provide benefit in their use. Recent studies have encouraged the use of these two concepts together however this has not been without challenges. The challenge that has been identified deals with how well a given company or firm is at maturity level in BIM. BIM at maturity levels provide different levels of enhanced efficiency to Lean construction. Not all levels will yield the same improvements in efficiency and therefor it is necessary for each firm to refine the choice they make in how much BIM and Lean Construction should be joined according to the company's capabilities (Hamdi & Leite, 2012) .

The development of more BIM tools in order lead to long lasting creations on this synergy being harnessed has led to beginning of the formation of creative ideas and novelty. This is shown whereby a prototype of an IT BIM tool named *KanBIM* was developed to act as a way to create the flow in the tasks. This concept of work flow is one of the principles of Lean that was being modelled into construction. As a prototype, the KanBIM system did show potential to have more efficient rates in construction, however the reliability of the tool was questioned and recommended for further improvement. The steps are being taken however to develop a long lasting collaboration between BIM and Lean Construction (Sacks, et al., 2013).

# Analysis

From the articles, a common thread that is present in all of them is the aim of making the construction process more efficient. They show that the two separate concepts of BIM and lean can be configured in ways that lead to an enhanced increase in efficiency. The studies however show that this is a new research topic with most of them being initial studies in this area thus availability of more research work is needed to be carried out.

The studies also show that there are numerous ways of looking at this for example through the different stakeholders, different construction process stages, different software packages, different framework of interaction and different methods of implementation.

From the studies, this paper has tabulated the interaction between Lean and BIM as below;

| Lean Construction | Intersection with BIM |
|---|---|
| Elimination of wastages (time, materials & effort) | Structural clash tests |
| | Design alternatives to select most suitable design |
| | Peformance simulations for the most efficient energy solution |
| Customer Value (achieve requirements) | Vizualization of solution that ensure clear understanding of the model |
| | Analysis for best result |
| | Understanding between client and supplier by use of 3D models and walk throughs |
| Reduced Cycle Times | Automated generation of changes and material shedules and quantities |
| | Provide accurate information to Prefabrication |
| | Visualizing of work flow to check for process conflicts (teams and tasks) |
| Work Flow | Through making detail schedules of tasks and materials delivery times |
| Collboration | Ability to work concurently on same design solution by different teams |

Table 1: Interaction between Lean principles and BIM

Utilization of BIM to ensure the production phase achieves the lean construction objectives. The different approaches that have been applied to construction are enhanced by BIM in the following ways;

- Just In Time (JIT); through the use of BIM, the planning process can be made to have more offsite works done. When the design is made then that information can be accurately passed on to the teams that will carry out the prefabrication.
- Concurrent Engineering; Working parallel in design is possible with the different disciplines than merged together. The information is easily available to the actors that require it.
- Last planner System (LPS); with 4D BIM, the planning process can be planned to detail in all the required levels, of master plan, phase plan and weekly plan.

BIM as a process has been evolving to use of new computer technology and the process' next step should be to integrate Lean Construction principles into the planning process, because this will lead to an integrated process, from the design phase into the production phase. Lean on its own or BIM applied on its own provides less benefits that they would be when applied together.

# Conclusion

The aim of this paper was to study in the interaction between Lean construction and BIM focusing mainly on the design phase in construction and investigate how they can be implemented in a way that leads to increase in efficiency in projects.
This was answered using the research questions in the literature review, findings and analysis chapters. The questions were

1. Investigate lean production principles and how they are applied in construction
    - In the literature review chapter, it was shown how the concept of lean originated from the Japanese automobile and then it was well defined in the principles which laid a platform for it to be applied into other industries like construction. In construction techniques such as Just In Time delivery, Concurrent Engineering and Last Planner System were applied that was built on Lean principles

2.Investigate BIM, its implementation and functions in design stage.

- In the Literature Review, a study was done on BIM showing it as a process that has evolved to different levels and dimensions. The adoption to BIM in construction industry is growing with the formation of a new role called the BIM managers to oversee the BIM process. BIM offers a number of benefits like providing 3D visualizations and clash detection.

3.Study how the lean principles in construction and BIM functionalities intersect in the design stage.

- The intersection between Lean and BIM has been a recent area of interest with various studies done to investigate this. The studies do reveal that even when the concepts are applied individually, they do have similar ways they improve efficiency, like in eliminating wastage. This leads to more studies that show much more that efficiency is enhanced when the two are applied together in projects.

4.Suggest ways in which synergies between lean construction and BIM can be successfully implemented.

- The synergy between Lean Construction and BIM can be well implemented if this collaboration is started early from the design phase so that desired principles of Lean construction are well planned and thus will be applied well in production stage too. Also the BIM tools like the software is evolving into form that ingrain Lean construction techniques like the formation of KanBIM, which employs the Kanban system in lean approach.

The research however has shown the beginning of the works in the interaction of Lean Construction and BIM and leaves a lot more room further studies to investigate more ways of having the combination of Lean and BIM from the early stages in construction to yield and integrated process. Also Research may be carried out about the challenges of having the combination of Lean Construction and BIM.

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