Reshaping Construction Management for Sustainability and Resource Efficiency: Implementation of LeanBIM Concept in Construction

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ABSTRACT

Construction is considered to be a high waste generating industry, in spite of its importance for human lives and economies. A lot of researches have been conducted to find out new ways to improve the way construction projects are managed. The main goals of these researches were to reduce the cost and time for projects as well as increase the quality of the final product.

In 1990's Lean Construction concept has been founded as an alternative for the conventional construction project management methodologies, based on Lean manufacturing concepts focusing on value and reducing waste in the construction processes.

Building Information Modeling (BIM) is a modern tool enabling intelligent model based process. BIM implementation has a lot of benefits to the construction, for instance, making use of visualization of the final product to facilitate communication between different disciplines and team members, enable what-if analysis and analyze the constructability of a building.

During the last decade, Pioneering contractors in US have realized the synergic fit between Lean and BIM. The interaction between Lean Construction and BIM has been the topic of many researches since then.

This research introduces the term "LeanBIM", which refers to the combination of the tools of Lean and BIM, and discuss their effects on sustainability and resource efficiency. An extensive review of literature is carried out and a survey is conducted on the Lean and BIM professionals and researchers from all over the world. The results showed the positive effect of LeanBIM implementation on sustainability of building as well as resource efficiency. LeanBIM is also expected to reduce the overall cost and time required for construction, and increase the quality. The results also showed that there is shortage in Lean/BIM professionals, lack of legal framework to enable the collaboration between all parties, lack of awareness of LeanBIM benefits. It is observed from the result that a considerable investment is required to form an IT infrastructure capable of implementing LeanBIM.

Keywords: Lean Construction, Building Information Modeling, Sustainability, LeanBIM, Resource efficiency, Construction Project Management.

ÖZ

İnşaat endüstrisi insan hayatı ve ekonomideki önemine rağmen yüksek oranda atık üreten bir endüstridir. İnşaat projelerinin yönetimini geliştirmek için birçok çalışmada yeni yöntemler araştırılmıştır. Bu araştırmaların ana amaçları projelerin maliyetini ve süresini düşürmek ve aynı zamanda son ürünün kalitesini de artırmaktı.

1990'larda Yalın İnşaat kavramı, yapım süreçlerinde değer ve atıkların azaltılmasına odaklanan yalın imalat kavramlarına dayanan geleneksel proje yapım yönetimi yöntemlerine alternatif olarak ortaya çıkmıştır.

Yapı Bilgi Modellemesi (YBM), akıllı model tabanlı süreçleri içeren modern bir araçtır. YBM uygulamasının yapım süreçlerini çok büyük katkıları vardır örneğin, farklı disiplinler ve ekip elemanları arası iletişimi sağlamak, ne-eğer analizlerini yapmak ve yapılabilirliği analiz etmek için son ürünün görselliğinden faydalanmak gibi.

Son on yılda, ABD'deki yenilikçi yüklenici firmalar yalın ve YBM arasındaki sinerji uyumunun farkına varmışlardır. Yalın inşaat ve YBM arasındaki etkileşim birçok araştırmanın konusu olmuştur.

Bu araştırmada Yalın ve YBM araçlarının birleşiminden doğan YalınYBM sunulur ve sürdürülebilirlik ve kaynak verimliliğine olan etkilerini tartışır. Geniş kapsamlı bir literatür çalışması yapıldı ve dünyanın çeşitli ülkelerindeki Yalın ve YBM konusunda çalışan uzman ve araştırmacılarla anketler gerçekleştirildi. Sonuçlar YalınYBM'nin kaynak verimliliği yanında sürdürülebilirliğin de olumlu etkisini göstermektedir.

YalınYBM'nin ayni zamanda yapım maliyetini ve süresini de düşürmesi, ve kaliteyi de artırması beklenmektedir. Sonuçlar YalınYBM uzmanlarının eksikliğinden, tüm taraflar arasında işbirliği sağlayacak yasal çerçevenin bulunmamasından, YalınYBM faydaları farkındalık eksikliğini göstermektedir. Yalın BIM uygulama yeteneğine sahip önemli miktarda bir yatırımın da bir BT altyapısı oluşturmak için gerekli olduğu ortaya çıkmıştır.

Anahtar kelimeler: Yalın İnşaat, Yapı Bilgi Modellemesi, Sürdürülebilirlik, YalınYBM, Kaynak verimliliği, İnşaat Proje Yönetimi

To my beloved family

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BIM	Building Information Modeling.
IPD	Integrated Project Delivery.
LC	Lean Construction.
LPS	Lean Production System.
LPDS	Lean Project Delivery System.
TPS	Toyota Production System.
WIP	Work In Progress

Chapter 1

INTRODUCTION

1.1 General

The importance of Construction Industry is derived from the human need of housing as well as the industry significant contributions to the economic growth of nations, directly through its activities or indirectly through its deliverables of buildings and infrastructures that facilitate business activities.

Construction Industry faces a lot of problems such as poor quality of the final products, time and cost overrun in addition to the harmful environmental impacts during the construction activities and buildings life cycle. The need for improved productivity, reduced waste in time and resources as well as less undesired environmental impacts for the industry is became very urgent with the construction boom we are living today.

In 1998 the Government Statistical service of the United Kingdom has reported that the waste produced by the construction industry is exceeding 70 million tons each year, which is about 4 times the waste production rate produced by every person in the United Kingdom (Keys et al., 2000).

1.2 Construction management and waste control

Construction is seen to be a series of activities intended to reach a certain output (Koskela, 1992). The construction process is usually broken down into main stages, and for each of these stages the cost of materials, machinery and manpower are estimated, a time frame is assigned for the completion of each of these stages. These stages are assumed to consist of activities that convert inputs into outputs and can only be accomplished separately. At each stage of construction or design processes wastes are directly or indirectly produced. The waste reduction through design is complicated as the amount of materials and number of activities can be very large for accomplishing a single product such as a building or infrastructure project (Koskela, 1992). In addition, the process becomes more complicated as more waste creators are added during various construction stages and also by sub-contracting (Keys et al., 2000). In spite of these shortage of the activity model, lack of a theoretical and conceptual framework in construction still exists. The focus on activities hides the waste generated between continuing activities by unpredicted resource delivery or release of work. In other words these current activities and production forms are take activities into consideration and ignore shortcomings and value considerations (Koskela, 1992).

With the increase of international competition and lack of skilled labors, there is an urgent demand to increase the quality, productivity and implement new technology to the industry (Koskela, 1992).

Wastes generated is also affected by many variables and restraints of the design process; such as the design complexity, Choice of the materials, coordination and communications between different disciplines (Keys et al., 2000).

The earlier researches mainly aimed to speed up the construction process and improve the overall productivity with introducing new technologies, tools and equipment keeping the same project management techniques. The focus was mainly on time-cost-quality tradeoff. However, Lean Construction which is a new form of project management reinforced by the powerful capabilities enabled by application of BIM are expected to provide different procedures and results, which are expected to help achieving efficiency in resources and more sustainable buildings.

1.3 Problem statement

The conventional construction management techniques are not suitable for today's complex projects. The construction boom we are living today raised the need for sustainable buildings and more environmental friendly construction processes which urge for embracing new project management tools and techniques. These tools and techniques should consider the nature of the construction industry with high waste generation, and focus on value delivered to the client. A change in construction industry, which is known by cost overruns, delays, lack of quality and Health & safety, has been long awaited. The synergy between the three concepts (Lean, BIM and Sustainability) can be considered as a major opportunity to reach such a change (Koskela et al., 2010).

1.4 Objective

The main objective of this thesis is to study the effects of embracing Lean concepts alongside with BIM in construction industry on resource efficiency and sustainability, and also identifying the challenges facing the implementation of Lean and BIM concepts. This is carried out through reviewing the previous researches that have been conducted to identify benefits of Lean and BIM as well as the interaction between there concepts. In addition to these, an online survey on industry professionals and researchers is carried out to measure their perceptions regarding achieving sustainability targets and waste reduction within the construction industry by implementing LeanBIM concepts.

1.5 Thesis organization overview

The thesis consists of five chapters; Chapter1 (Introduction) an introduction about the thesis. Chapter2 (Literature review) presents an extensive literature study for different types of waste in construction, Lean Construction and BIM concepts, benefits of implementing them within the industry, their applications and the interaction between them. Chapter3 (Research Methodology) provides a description of the methodologies followed in this research. Chapter 4 (Results and discussion) provides discussion of the results and findings from the survey and literature. Chapter5 (Conclusion) addresses overall summary from the study, important findings, opportunities for improvements and suggested further area of research.

Chapter 2

LITERATURE REVIEW

2.1 General

In order to study the benefits of implementing Lean Construction and BIM concepts, a review of literature is prepared, focusing on various types of waste produced in construction. The interaction of Lean Construction and BIM in projects is reviewed to develop the definition of the term LeanBIM. The general requirements for sustainable design are addressed to discuss how LeanBIM implementation can affect the sustainability of buildings.

2.2 Waste in Construction

2.2.1 What is waste?

Waste is defined as anything that is larger than the minimum quantity of equipment, materials, parts and labor time that is absolutely required for production of a building. Waste includes the loss in materials as well as the unnecessary work executed which generate additional costs without adding value to the final product (Koskela, 1992). *"In short, waste is anything the customer is not happy to pay for"* (Tommelein, 2015).

A lot of researches about waste in construction have been conducted, however the majority of these studies have focused on the waste in materials which represents only one resource of the construction process. This is considered to be the reason that the current construction processes involve huge amounts of wastes, loss of value and non-value adding activities (Formoso et al., 1999).

Agopyan et al. (1998) conducted a two year study coordinated by The Brazilian Institute for Technology and Quality in Construction (ITQC) on material waste measurement, involving 15 universities and more than 100 building sites. Formoso et al. (1999) summarized the main conclusions as;

- The real values of waste in building materials are higher than the estimated values in companies' cost estimation.
- Waste indices showed high variability from site to site. Furthermore, different levels of waste might have been presented from similar sites for the same material, which indicates the possibility to avoid a significant portion of waste.
- Some companies seem not to be concerned about waste in material, as they do not apply relatively simple procedures to avoid waste in sites. These companies seemed not to be applying a well-defined material management program or organized material usage control.
- Most of building firms are not aware enough about the amount of waste they have, and so how to prevent it.
- Problems occur in stages before the production stages such as poor planning, inadequate design, and shortage in material supply system, etc. is the mean reason behind the biggest portion of waste.

According to Formoso et al. (1999) the contribution of this kind of researches for founding waste control systems has been somewhat limited and that is due to the following reasons:

- The majority of studies are focusing on the waste of materials which represent only one resource of waste in the construction. That because of the fact that most of these studies was conducted based on the dominant fact that waste of material is considered to be the synonymous of waste.

- The huge expenses behind the process of data collection in addition to requirement for a large team of researchers and people to monitor the work on site. Due to that, the waste controlling procedures used in research studies are not easily adapted in real time production control systems.
- The impacts of these studies in terms of corrective actions are very limited, as producing results out of these studies usually take a long time.
- The limitation of learning process resulting from these studies for companies as most of waste control procedures are external to these companies since most of people involved in data collection and analysis are not from the organization.

2.2.2 Classifications of wastes

According to Formoso et al. (1999), waste can be classified into unavoidable waste (natural waste), in which the value gained from its reduction is lower than the investment required to reduce it, and avoidable waste, in which the cost of waste is significantly higher than the cost of preventing it. The amount of unavoidable waste depends on the particular site, nature of the project and the organization (as it depends on the technology implemented).

Waste can also be categorized according to its origins, i.e. the stage in the process related to the root cause of waste. Usually waste is identified within the production stage, however, there is a possibility for the waste to be originated by processes that come before the production stage, such as planning, design, material manufacturing and supply and training of manpower.

According to Shingo (1989), Waste can be classified into seven types according to its nature, the eighth waste – underutilized workers' talents - was introduced by Bodek (2007), and that is how it is identified and dealt with in Lean practices:

2.2.2.1 Waiting time

It is the idle time or delay that caused by lack of levelling and synchronization of material flows, and pace of work by different groups or equipment (Formoso et al., 1999). The inactivity periods occurs when people, equipment or process wait for preceding activities to be completed increase the cycle time due to a non-value added activities. This delay usually occur because of lack of communication between field operations, support operations and suppliers. Also when equipment that required to complete the preceding activity breaks down or not adequate to the job. It also happen when a crew in a construction site are waiting for materials, drawings or instruction to start an activity.

2.2.2.2 Movement or motion

The unnecessary or inefficient movements done by workers during their job. Poor arrangement, inadequate equipment or ineffective work methods could be reasons for this waste (Formoso et al., 1999). These extra steps and movements by people not only consume time but it add no value to the final product or service as well.

2.2.2.3 Transportation

The unnecessary material movement on site that do not support the production process. It can be produced due to the use of inadequate equipment, excessive handling or bad condition of roads. The main reasons usually are poor layout and lack of material flows planning. As a result of these activities a waste of time, energy, space on site and material may occur (Formoso et al., 1999). The more movement of materials the bigger will be the chance to damage and waste (Banawi & Bilec, 2014).

2.2.2.4 Processing and over processing

It is directly related to the nature of the processing activity and the processing method applied. For example the wasted mortar when plastering a ceiling (Formoso et al., 1999).

2.2.2.5 Inventories

The unnecessary or excessive inventories exceeding the production requirements lead to material waste; for example, inadequate stock conditions, material deterioration, being susceptible to robbery or vandalism. The tied up capital due to the unused materials is considered a monetary loss as well. Uncertainty of estimation of quantities as well as lack of resource planning might be the main reasons behind this waste (Formoso et al., 1999).

2.2.2.6 Over Production

It occurs when production operations continue when it should be stopped. So, the production is more, faster than or before it is needed, results in unnecessary inventory, material and manpower consumption (Banawi & Bilec, 2014).

2.2.2.7 Correction or defects

It happens when the final or intermediate product doesn’t meet the quality specifications (Formoso et al., 1999). This may lead to extra work making it harder to perform priority activities.

2.2.2.8 Underutilized people

Not making use of people creativity, mental and physical abilities efficiently (Garrett & Lee, 2010).

2.3 History of Lean Construction

2.3.1 History of Lean production

The term "Lean Production" was first introduced by John Krafcik of MIT International Motor Vehicle Program as a new production methodology in which less resources, manpower, manufacturing space, engineering hours, tools and inventory warehouses are used in mass production (Womack et al., 1990). Japanese Toyota's Engineers Ohna and Shingo have developed The Toyota Production System (TPS) following Henry Ford's flow-based production management, which includes the advantages of mass production as well as craft production. The main goals of TPS were customer satisfaction, zero waste, zero inventory and product perfection.

Lean thinking is focusing on value generation more than how one activity can be managed (Howell, 1999). Lean thinking considers the entire project as if it was one large operation, unlike the current project management methodologies which consider the project as combination of activities.

In the Lean production model, production is managed with full focus on the value produced to the customer. The total cost and duration of the project have more importance than the cost or duration of any single activity. Generally, coordination is accomplished by central schedule while the workflow details are managed through the organization by people who are aware of and support project goals (Howell, 1999). Value, throughput and the movement of information and materials to completion are the primary objectives of Lean production theory.

In a production system, waste can be defined according to the performance criteria. If the unique requirements of the client are not met, then this is considered to be waste.

Waste can be reduced by reducing the difference between the current situation and the perfection (Howell, 1999).

2.3.2 Lean Construction (LC)

The term "Lean Construction" was coined by Glen Ballard and Gregory Howell in 1990s by embracing the Ohno's production system design criteria as a standard of perfection. Unlike the manufacturing where different parts are made to assemble the final product, designing and constructing a unique project in highly uncertain environment under the pressure of time and schedule is totally different. Transformation the Lean Production System (LPS) concepts to the construction industry was initiated by many researchers (Womack & Jones, 1996).

Lean Construction is a project delivery system based on the concept of production management ensuring the reliability and speed of value delivery. Challenging the project management main beliefs of time, cost and quality trade-off. Generally, the work on Lean Construction is governed by two major concepts; Koskela's Transformation-Flow-Value concept and Last Planner methods of production control by Ballard and Howell.

According to Koskela (2000), LC is based on two production theories: flow and value generation. First, the flow concept focuses on the waste reduction. Second is the value generation concept takes into consideration the value delivered to the customer. The Lean Construction practices and methods based on both of these concepts are significantly different from those based on the traditional transformation concept of production which sees production as transformation of inputs into outputs (Koskela, 2000).

2.3.3 Lean Project Delivery System (LPDS)

Lean Project Delivery System (LPDS) is a construction management methodology inspired by Toyota Production System (TPS), focusing on producing value without generating waste. LPDS takes the cooperation to the next level by forming a team in which the architect, builder and all other critical players in the project are treated as equals on a single team to meet client goals (Jr. & Michel, 2009).

Figure 2.1 introduces an LPDS schema as a series of phases represented as overlapped triangles. The first phase is "Project Definition" in which customer's purpose, design concepts and customer's constrains are represented. These elements may influence each other, which makes the conversation between different stakeholders necessary, that everyone leaves with a better understanding than they brought with them (Ballard & Howell, 2003; Ballard, 2008).

In the LPDS the project delivery team's job is assumed not only to provide what the customer want, but to first help the customer to decide what they want. Hence it becomes necessary to understand customer purpose and constrains, and introduce the alternative means of accomplishing these purposes to the customer beyond those they have previously considered. The process also helps customers understand the consequences of their desires (Ballard, 2008).

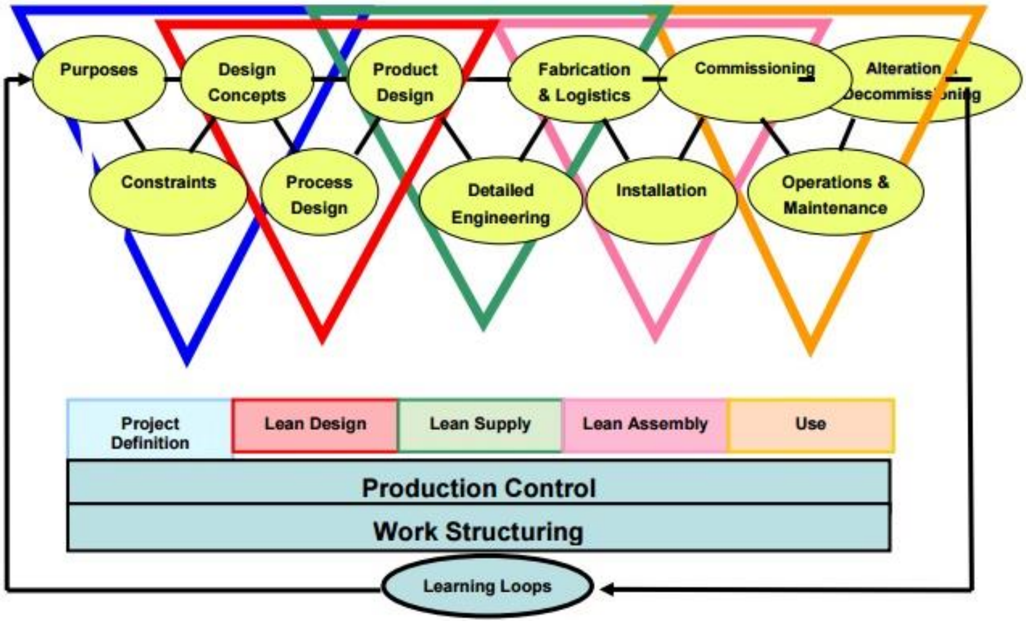

Figure 2.1: Lean Project Delivery System (Ballard, 2008)

2.3.4 Fundamental Lean principals

As a result of Lauri Koskela's work; the following list of principles thought to be important to Lean production (Diekmann et al., 2004):

2.3.4.1 Meeting customer's requirements

Quality as defined by customer requirements must be considered. The production success depends on the customer satisfaction. As a practical approach, the customer requirements should be defined and analyzed for each production stage.

2.3.4.2 Reducing non-value adding activities.

There are three more sources of non-value added activities:

- Production system structure, which determine the physical flow to be overpassed by information and material.
- Production system controlling manner.
- Production system nature, such as machine breakdowns, accidents or defects.

2.3.4.3 Reducing cycle time

Cycle time is the total time required for a particular piece of material to overpass the flow. It can be represented as:

Cycle time = Processing time + Inspection time + Waiting time + Moving time

The following activities have been identified to reduce cycle time:

- Eliminating work in progress (WIP).
- Reducing batch size.
- Changing plant layout to minimize the moving distance.
- Keeping things moving; smoothing and synchronizing flows.
- Reduce variability.
- Separating the main value adding sequence from support activities.
- Changing the activities ordering from sequential to parallel.

2.3.4.4 Reducing Variability

Variability increases cycle time; variability of activity duration increases the volume of non-value adding activities. The reason behind variability reduction is to reduce the products' nonconformance as well as the variability of duration of value adding and non-value adding activities. Following are variability reduction strategies:

- Activity standardization, this can be done by implementing standard procedures.
- Mistake-proofing devices.

2.3.4.5 Increasing flexibility

Increasing the production line ability to meet the market demand and change. According to Stalk (1990), the following activities can increase the output flexibility:

- Lot size minimization to closely match the demand.
- Difficulty of setup and changeover reduction.

- Customizing as late in the process as possible.
- Multi-skilled workforce training.

2.3.4.6 Increasing transparency

To facilitate mistakes locating and quickly solving them, the entire flow operation must be made visible and comprehensible to those involved.

2.3.4.7 Maintaining Continuous improvement

Continuous improvement of operations and management techniques must be undertaken. The following methods are considered necessary for continuous improvement:

- Improvement measuring and monitoring.
- Stretch targets setting, by which problems can be identified and solved.
- Giving all employees the improvement responsibility; steady improvement should be required and rewarded from every division within the organization.
- Using standard procedures as a best practice propositions so that it can be constantly challenged by better ways.
- Linking improvement to control; the point of improvement should be eliminating the roots of the current control constraints and problems of the process rather than getting over their effects.

2.3.4.8 Simplifying by minimizing the number of steps, parts and linkages

Complexity produces waste and additional costs. When possible the process should be streamlined through efforts such as consolidating activities; standardizing parts, tools and materials and minimizing the amount of control information needed.

The following considered practical approaches to simplification:

- Shortening flows by consolidating activities.
- Reducing the parts of products through design changes or prefabricated parts.

- Standardizing parts, tools, material…etc.
- Decoupling linkages.
- Minimizing the amount of control information needed.

2.3.4.9 Focusing control on the complete process

Segmented flow should be avoided as it leads to sub-optimization; for optimal flow, control should be focused on the entire process.

2.3.4.10 Balancing flow improvement with conversion improvement

Both flow and conversion improvement are interrelated, to create balance within the process their individual improvement should be analyzed.

2.3.4.11 Benchmarking

Benchmarking can trigger breakthrough improvement through radical reconfiguration of processes.

2.3.5 Lean Construction tools and techniques

The tools and techniques implemented to achieve Lean Construction has been discussed by (Salem et al., 2006) they can be summarized as shown in Table 2.1.

Table 2.1: Lean tools (O. Salem et al., 2006)

Scope	**Technique**	**Requirements**	**Criteria/change**	
Flow variability	Last planner	Reverse phase	Pull approach	↑
		Scheduling	Quality	↑
		Six-week look-ahead	Knowledge	↑
		Weekly work plan	Communication	↑
		Reasons for variance	Relation with other tools	↑
		PPC Charts		↑
Process variability	Fail safe for quality	Check for quality	Actions on the job site	↑
		Check for safety	Team effort	↑
			Knowledge	↑
			Communication	↑
			Relation with other tools	↑

Transparency	Five S's	Sort	Action on the job site	↑
		Straighten	Team effort	↑
		Standardize	Knowledge	↑
		Shine	Communication	↑
		Sustain	Relation with other tools	↑
	Increased visualization	Commitment charts Safety signs	Visualization Team effort	↑
		Mobile signs	Knowledge	↑
		Project milestones	Communication	↑
		PPC charts	Relation with other tools	↑
Continuous improvement	Huddle meetings	All foreman meeting	Time spent	↓
		Start of the day meeting	Review work to be done	↓
			Issues covered	↑
			Communication	↑
			Relation with other tools	↑
	First-run studies	Plan	Actions on the job site	↑

		Do	Team effort	↑
		Check	Knowledge	↑
		Act	Communication	↑
			Relation with other tools	↑

2.3.6 Differences between Lean Construction and traditional construction management

Lean Construction philosophy is significantly different from the traditional project management practices which is based on the Project Management Body of Knowledge (PMBOK) established by the Project Management Institute (PMI), according to (Forbes & Ahmed, 2011) these differences can be summarized as bellow:

- Lean Construction focus on the whole project as a one unit while traditional project management practices focus on the activities.
- Better short term planning and control.
- Lean Construction doesn’t replace the traditional schedule defining tools like Critical Path Method (CPM). It works within them to improve the delivery of short term assignments.
- Lean Construction sees planning effectiveness to be limited because of the unplanned actions, which usually happen. Embracing scheduling techniques,

focusing on the short-term horizon like The Last Planner is considered more effective.

- Lean Construction concerns with value, unlike traditional project management concepts, which mainly focus on schedule and cost control.
- Focusing on learning and flexibility gives Lean Construction the better ability to deal uncertainty and unplanned actions specially in complex projects, while CPM is in fact an approximation of how work should be done and it is less effective in handling the details of how can actually be done.
- Generally, PMBOK works well with relatively simple and predictable projects, while Lean Construction is seen to be more effective in handling the complexity and uncertainty of projects, because of the flexible nature and learning new lessons that can be applied in planning of consecutive stages of the project.

2.3.7 Applications of Lean concepts in construction industry

The aim behind implementing Lean principles into the construction industry is to fill the gaps of the traditional construction management approach, the following summarize the different applications of Lean thinking in construction:

2.3.7.1 Construction supply chain

According to studies conducted to show the advantages of applying Lean concepts to construction supply chains, the conclusion shows that implementing of Lean concepts such as value stream analysis, batch size reduction, early involvement of suppliers in design stage, process standardization, and improve supplier selection, is an effective way to improve the supply chain performance by helping identifying wastes within the process (Fontanini & Picche, 2004; Tommelein, 2002).

2.3.7.2 On-site subcontractor evaluation

A study conducted in Chile to develop a method for evaluation of subcontractors based on Lean concepts. This method was achieved through periodic evaluation and improving of communication between subcontractors and main contractor by using visualization tools. This method helped in solving many clashes, and helped subcontractors' supervisors to monitor their workers on-site performance. It also helped the main contractor in choosing suitable subcontractors for future work based on the performance history (Maturana et al., 2007).

2.3.7.3 Finishing work in buildings

The efficiency of workflow of internal finishing work is a complicated task because of the unviability of design information at certain stages and allocating teams in available work zones to prevent the accumulation of work in progress (WIP). In an attempt to solve this problem, Lean concepts can be implemented through visualization of the process on site by using status board generator software using small icons drawing in each cell that indicate the work status and the future work as well. This status board can help the work supervisor to efficiently allocate his team by viewing the near future work, work should be done and the rework required. The status board can also help in progress monitoring and making the project status information available to all management levels. Accordingly, novel computer aided visualization tools can improve the workflow by revealing the rate of progress and the bottlenecks of the process (Sacks et al., 2009).

2.3.7.4 Construction submittals

In delay in construction submittal process can negatively affect the project schedule. Therefore improving the office activities is important for better workflow on site. Lean Construction concepts were applied in office processes as the submittal process in some construction firms in San Diego and considerable improvements have been noticed. These improvements includes time reduction mainly be eliminating wastes and reducing non value adding activities (Garrett & Lee, 2010).

2.3.7.5 Improving labor workflow in construction

Several studies have been conducted to examine the impact of reliable workflow as a Lean principle on labor workflow. In a study conducted on 2003 involved construction of 3 bridges covering 137 workdays. The flexible capacity approach was addressed as a potential area for improving construction performance, the conclusion was that ineffective labor flow leads to ineffective flow management. (Thomas et al., 2003).

H. Randolph et. al (2002) conducted a study to examine the issue of variability in construction and its impact on project performance using data from 14 concrete formwork projects. They concluded that reducing the variability in labor productivity is more intensely correlated to better performance than reducing workflow variability (Thomas et al., 2002).

2.3.7.6 Formwork engineering

Using Lean concepts in formwork engineering can reduce resources and wastes and increase the operational value, these improvements come from the fact that Lean Construction reduces the wastes result from walking and searching in mold assembly and machining (Ko et al., 2011).

2.3.7.7 Construction projects

When implemented Lean Construction techniques in a project of constructing 80 housing units in Nigeria, the results showed time management improvements which lead to saving in project cost, the project was completed in 62 days instead of 90 days (Adamu & Hamid, 2012).

2.3.7.8 Precast concrete fabrication

Implementing Lean concepts in manufacturing of precast concrete reduces lead and cycle time, increase throughput rate and improve the productivity (Ballard et al., 2003).

2.3.7.9 Infrastructure projects

A study conducted on a tunneling project to implement Lean techniques, the results was increasing of the productivity by 43%, the project was on schedule and no delays were experienced. Also then profits was doubled (Wodalski et al., 2011).

2.4 Integrated Project Delivery (IPD)

In 2014 the American Institute of Architects California Council (AIACC) has updated IPD definition as:

> A project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction (AIACC, 2014).

According to AIACC (2014), as a minimum the IPD method must contains all of the following:

- Continuous involvement of owner, key designers and builders from early design through project completion.
- Business interest aligned through shared risk/reward, including financial gain at risk that is depend upon project outcome.
- Owner involvement in project control with and key designers and builders.
- A multi-party agreement or equal interlocking agreements.
- Limited liability among owner, key designers and builders.

2.5 Building information Modeling

BIM has different definitions in the literature, however, Succar (2009) introduced the different definitions for BIM as shown in Figure 2.2.

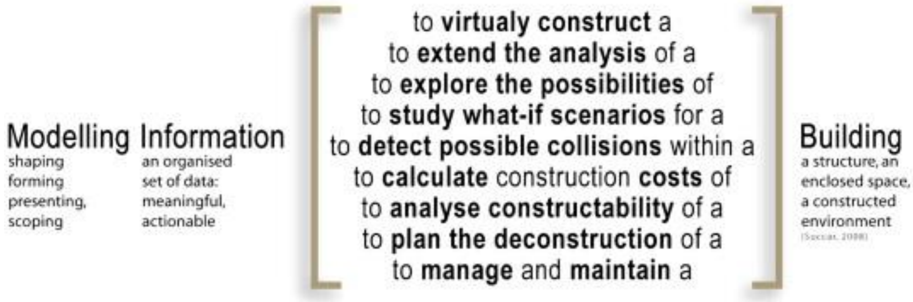

Figure 2.2: Some common suggested terms for BIM (Succar, 2009)

According to The US National Building Information Model Standard Project Committee, Building information modeling (BIM) is defined as "Digital representation of physical and functional characteristics of a facility". A more comprehensive definition was proposed by (Arayici & Aouad, 2010):

> BIM is defined as the use of the ICT technologies to streamline the building lifecycle processes to provide a safer and more productive environment for its occupants, and to assert the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle.

Buildings became more complicated, and in the same time, understanding is very important for all stakeholders, and being part of the construction process from design phase to the actual operation. Use of BIM facilitates the communication between different disciplines and team members within the construction process (Sanvido, 2008). By utilizing a database containing built facilities with different points of view of the stakeholders. It is a methodology to accurately combine the digital description of building's objects with their relationships to others in order to facilitate querying, simulating and estimating of activities and their effects on the building process as a lifecycle entity. Therefore BIM can help with providing the required value judgements for creating a more sustainable infrastructure, which satisfy their owners and occupants (Arayici & Aouad, 2010).

2.5.1 Applications of BIM

According to Azhar (2011), BIM can be used for the following purposes:

- Visualization: With little efforts 3D models can be easily generated.
- Shop drawing and fabrication: Using BIM make it easy to generate shop drawings for different building systems once the model is complete.
- Code reviews: A BIM model facilitates the review of building projects for compatibility with codes.
- Cost estimating: different BIM software come with a built-in material take off and cost estimating features, any changes to the model automatically reflected to the estimated quantities and costs.
- Construction sequencing: BIM models can help in coordinating materials purchasing, fabrication and delivery schedules for different building components.
- Early conflict detection: the 3D nature of BIM models make it easy to automatically check for any confliction or interference between different systems within the building.
- Forensic Analysis: using BIM model make it easy to illustrate potential failures, leaks, evacuation plans and so forth.
- Facilities management: BIM model facilitates space planning, renovations, and maintenance operations for buildings.

2.5.2 Benefits of BIM

The main benefit of BIM is its accurate geometrical representation of the parts of a building in an integrated data environment (Cooperative Research Centre (CRC) for Construction Innovation, 2007). More related benefits are below:

- Faster and more effective processes: easy sharing for information among different parties, in addition to the ability to re-use these information.
- Better designs: the ability to analyze, simulate performance quickly and effectively enabling improved and innovative solutions.
- Controlled whole-life costs and environmental data: life cycle costs are clearer and more understood, and environmental data and impacts and more predictable.
- Higher production quality: Flexibility and automation of documentation output.
- Automated assembly: Digital product data can be used within downstream processes for manufacturing and assembly of structural systems.
- Better customer service: more understandable proposals due to the higher visualization accuracy.
- Lifecycle date: Better facilities management due to the ability to make use of information from different phases such as requirements, design, construction and operational information.

According to a technical report based on 32 BIM projects published by Center for Integrated Facility Engineering (CIFE), Stanford University, the following BIM benefits were addressed (Gilligan & Kunz, 2007):

- Up to 10% saving of contact value due to clash detections.
- Up to 40% reduction of unbudgeted change.
- Up to 7% reduction in project delivery time.

- Up to 80% reduction in cost estimation time.
- 3% cost estimation accuracy.

2.5.3 Challenges facing BIM adoption

In spite of the rapid year-on-year growth of BIM awareness and adoption till 2014, year 2015 statistics showed a pause in BIM adoption (National Building Specification, 2015). The common challenges that facing BIM adoption can be summarized as following:

- The adoption of BIM can be time consuming due to transition to a new technology (Latiffi et al., 2015).
- The initial cost of adoption of BIM is high due to the technology and hardware costs that only large organization can afford (Latiffi et al., 2015).
- To implement BIM in an organization, it needs to train their employees as well as hire new staff who are skilled and knowledgeable about BIM which requires costs reallocation for the organization (Latiffi et al., 2015; Arayici, et al., 2011).
- The required collaboration and interoperability between structural, MEP engineers and designers (Arayici, et al., 2011).

2.6 Sustainability in construction

Sharlyn Underwood, American Society of Interior Designers (ASID) Virginia chapter president and interior designer with Smith Lewis Architecture, defines sustainable design as “The practice of designing buildings so that they exist in harmony with natural systems.” In order to achieve sustainability in construction it is necessary to use design principles, construction materials methods and operational procedures that minimize the negative environmental impacts throughout all the construction phases of planning, designing, constructing and operating (Xia et al., 2013; Wu & Low, 2010; Hoffman & Henn, 2008).

There are three principles for sustainable design are shown in Figure 2.3 and listed below (Kim & Rigdon, 1998):

2.6.1 Economy of resources

Economy of resources considers concerns about reduction, reuse and recycling of natural resources that used in the construction processes by reducing the use of non-renewable resources during construction and operation of the buildings. This cycle begins with building material production and continues throughout the building useful life to maintain an environment for sustaining human activities. After a building's useful life, it should turn into components for other buildings. Figure 2.4 shows the resource flow conservation. For a given resource its form before entry to a building and after exit will be different (Kim & Rigdon, 1998).

2.6.1.1 Energy conservation

Buildings operations required a constant flow of energy input. The environmental impacts of energy consumption by buildings occur mainly away from the building site, through mining, harvesting energy sources and generating power. The energy consumed by a building in the process of heating, cooling, lighting and equipment operation cannot be recovered (Kim & Rigdon, 1998).

2.6.1.2 Water conservation

Buildings require a large quantity of water for the purposes of drinking, cooking, washing, etc. All of these water required treatments and delivery which consume energy. Sewage water that exits the building must also be treated (Kim & Rigdon, 1998).

2.6.1.3 Material conservation

In the construction phase a range of construction materials is used in the construction site, generating a significant amount of waste. After construction, a low-level flow of materials continues to in forms or maintenance, consumer goods, etc. All of these materials are eventually output, either to be recycled or dumped in landfills (Kim & Rigdon, 1998).

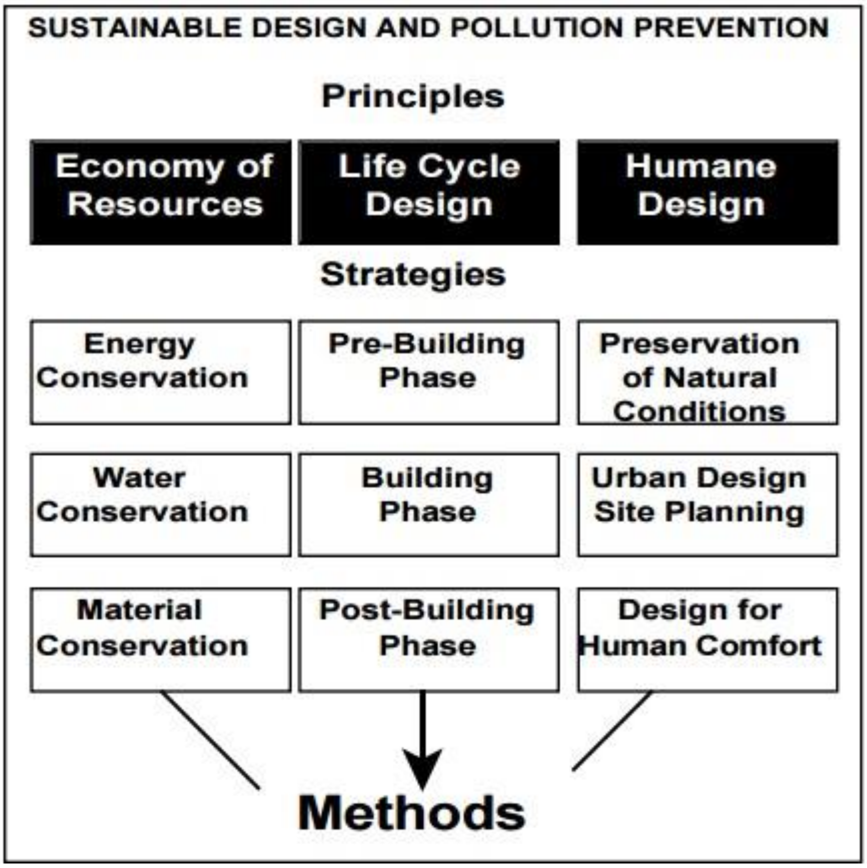

Figure 2.3: Conceptual framework for Sustainable Design and Pollution Prevention in Architecture (Kim & Rigdon, 1998)

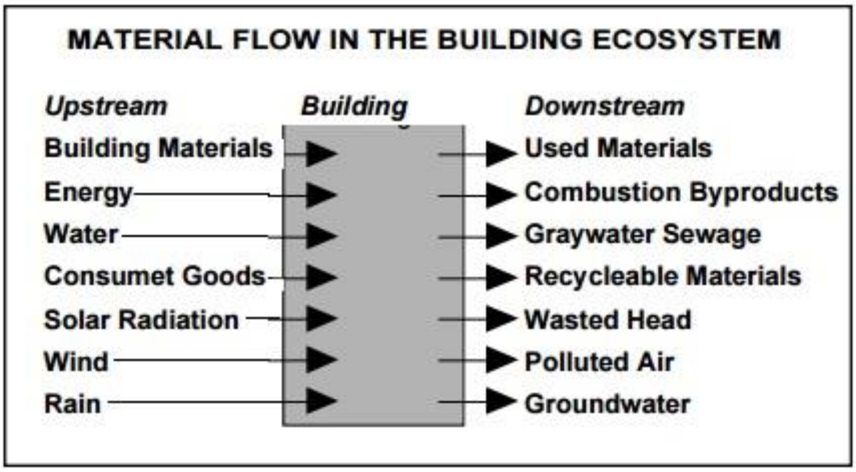

Figure 2.4: The input and output streams of resource flow (Kim & Rigdon, 1998)

2.6.2 Life cycle design

Life cycle design is the methodology of analyzing the building process and its impact on the environment. The conventional model of building life cycle is a linear process consisting of four major stages: design; construction; operation and maintenance; and demolition (see Figure 2.5). The main problem with this model is that it does not address environmental issues or waste management (Kim & Rigdon, 1998).

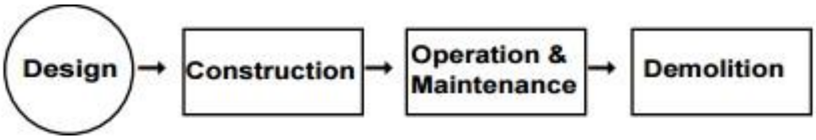

Figure 2.5: Conventional model of the building life cycle (Kim & Rigdon, 1998)

The second model is life cycle design (LCD). This approach recognizes environmental consequences of the entire life cycle of resources from procurements to return to nature (see Figure 2.6). LCD is based on the notation that a material transforms from one form to another, with no end of its usefulness (Kim & Rigdon, 1998).

- Pre-building phase
- Building phase
- Post-building phase

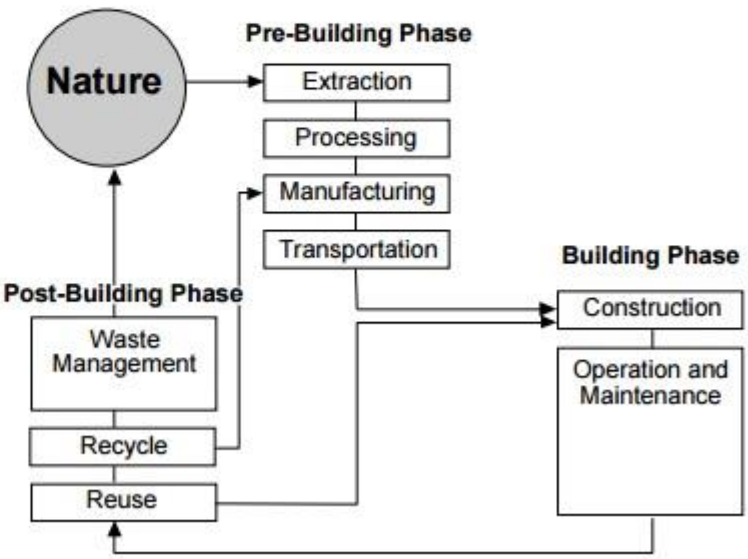

Figure 2.6: The sustainable building life cycle (Kim & Rigdon, 1998)

2.6.3 Humane design

This principle arises from the humanitarian and altruistic goal of respecting the life and dignity of fellow living organisms. Humane design concerns about the interaction between humans and the natural world represented in livability of all constituents of the global ecosystem, including plants and wildlife. This principle is deeply rooted in the need to preserve the chain elements of the ecosystems that allow human survival (Kim & Rigdon, 1998).

2.7 LeanBIM

The term LeanBIM has no clear definition in the literature, however it may be defined as implementing BIM along with Lean concepts in order to maximize the generated value with minimum possible resources and waste to a degree which is more improved than that of implementing either of them independently.

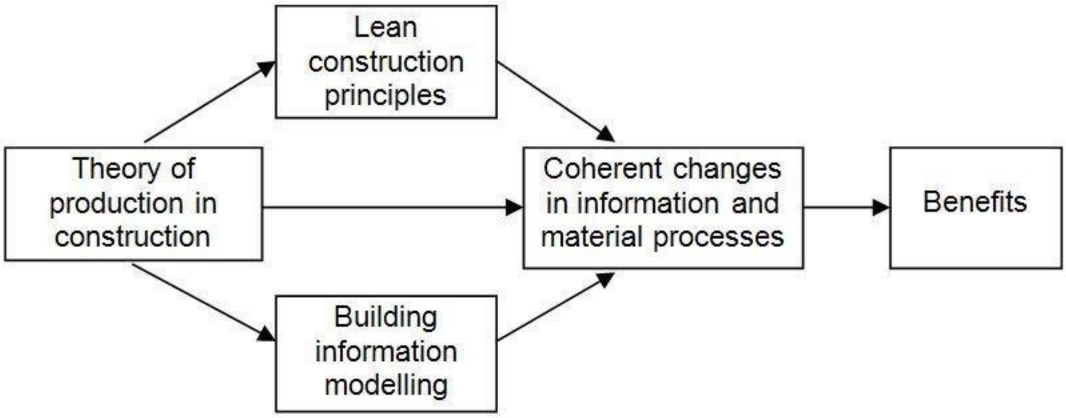

Figure 2.7: The dependence of benefit realization through process change in construction on Lean Construction principles, BIM, and a theoretical understanding of production in construction (Sacks et al., 2010)

Lean Construction and Building Information Modeling (BIM) have been severally applied separately to improve the construction industry, however in the last decade the implementation of both of them has reached an advanced level which made it clearer that both of the initiatives have a considerable mutual synergy, and that will be of high advantage to jointly implement them (Dave et al., 2013; Koskela, 2014). It is assumed that the full potential for construction projects improvement can only be reached when their adoption is integrated, as they are in the IPD approach (Sacks et al., 2010).

2.7.1 The relation between Lean Construction and BIM

The main goals of Lean Construction can be summarized as minimizing waste and generating value, this value can be maximized by implementing BIM alongside with Lean concepts. Figure 2.8 shows the four main mechanisms for the interaction of Lean Construction and BIM (Dave et al., 2013).

1. BIM contributes directly to Lean goals.
2. BIM enables Lean processes, which contributes indirectly to Lean goals.
3. Auxiliary information system, enabled by BIM, contribute directly and indirectly to Lean goals.

4. Lean processes facilitate the adoption and use of BIM.

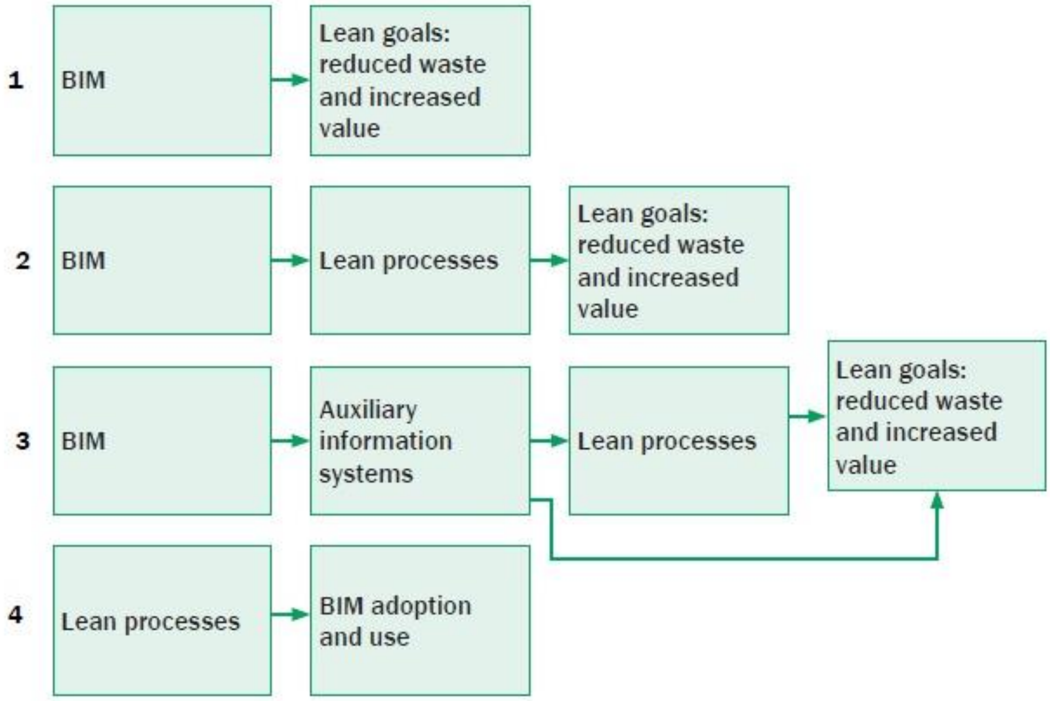

Figure 2.8: Conceptual connections between BIM and Lean (Dave et al., 2013)

A research has been conducted by (Sacks et al., 2010) to analyze the interaction of Lean and BIM, the analysis results are shown in Figure 2.9, Table 2.2 and 2.3 showing Lean principles and BIM functionalities respectively.

Lean Principles / BIM Functionality		Reduce Variability		Reduce cycle times		Reduce batch sizes	Increase flexibility		Select an appropriate production control approach		Standardize	Institute continuous improvement	Use visual management		Design the production system for flow and value				Ensure comprehensive requirements capture	Focus on concept selection	Ensure requirements flowdown	Verify and Validate	Go and see for yourself	Decide by consensus consider all options	Cultivate an extended network of partners
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Visualization of form	1	✓													✓				✓		✓	✓	✓	✓	
Rapid generation of design alternatives	2	✓		✓									✓	✓		✓									
Re-use of model data for predictive analyses	3	✓	✓	✓			✓												✓	✓		✓			
	4		✓	✓												✓				✓		✓			
	5	✓	✓	✓															✓	✓	✓	✓			
Maintenance of information and design model integrity	6	✓	✓																		✓				
	7	✓	✓	✓																		✓			
Automated generation of drawings and documents	8	✓		✓	X	✓											✓	✓							
Collaboration in design and construction	9			✓						✓						✓									
	10	✓		✓				✓											✓		✓	✓		✓	
Rapid generation and evaluation of multiple construction plan alternatives	11	✓		✓	X		✓								X										
	12		✓	✓	X					✓					X					✓		✓			
	13	✓	✓	✓	X						✓		✓	✓		✓						✓		✓	
Online/electronic object-based communication	14		✓	✓	✓	✓			✓					✓			X					✓	✓		
	15	✓		✓	✓	✓			✓		✓		✓	✓			X				✓			✓	
	16	✓		✓			✓																		
	17		✓	✓					✓								X								✓
	18		✓		✓	✓			✓			✓					X					✓	✓		

Figure 2.9: Interaction matrix of Lean principles and BIM functionalities. (X) represents negative interactions (Sacks et al., 2010)

Table 2.2: Lean Principles (Sacks et al., 2010)

Principal area	Principle	Column Key
Flow process	**Reduce variability**	
	Get quality right the first time (reduce product variability)	A
	Focus on improving upstream flow variability (reduce production variability)	B
	Reduce cycle times	
	Reduce production cycle durations	C
	Reduce inventory	D
	Reduce batch sizes (strive for single piece flow)	E
	Increase flexibility	
	Reduce changeover times	F
	Use multi-skilled teams	G
	Select an appropriate production control approach	
	Use pull systems	H
	Level the production	I
	Standardize	J
	Institute continuous improvement	K
	Use visual management	
	Visualize production methods	L
	Visualize production process	M
	Design the production system for flow and value	
	Simplify	N
	Use parallel processing	O
	Use only reliable technology	P
	Ensure the capability of the production system	Q
Value generation process	**Ensure comprehensive requirements capture**	R
	Focus on concept selection	S
	Ensure requirement flowdown	T
	Verify and validate	U

Problem-solving	**Go and see for yourself**	V
	Decide by consensus, consider all options	W
Developing partners	**Cultivate an extended network of partners**	X

Table 2.3: BIM Functionality (Sacks et al., 2010)

Stage	Functional area and function	Row Key
Design	**Visualization of form**	
	Aesthetic and functional evaluation	1
	Rapid generation of multiple design alternatives	2
	Re-use of model data for predictive analyses	
	Predictive analysis of performance	3
	Automated cost estimation	4
	Evaluation of conformance to program/client value	5
	Maintenance of information and design model integrity	
	Single information source	6
	Automated clash checking	7
	Automated generation of drawings and documents	8
Design and Fabrication Detailing	**Collaboration in design and construction**	
	Multi-user editing of a single discipline model	9
	Multi-user viewing of merged or separate multi-discipline models	10
Pre-construction and Construction	**Rapid generation and evaluation of construction plan alternatives**	
	Automated generation of construction tasks	11
	Construction process simulation	12
	4D visualization of construction schedules	13
	Online/electronic object-based communication	
	Visualizations of process status	14
	Online communication of product and process information	15
	Computer-controlled fabrication	16

	Integration with project partner (supply chain) databases	17
	Provision of context for status data collection on site/off site	18

2.7.2 Benefits of implementing BIM and Lean together

BIM is recognized as an emerging technology that can improve projects delivery, however the full benefits of BIM haven't been achieved yet. The integration of other technologies with BIM must work together with proper management strategies and approaches. This is assumed to be a vital step in closing the loop of BIM challenges (Wang & Chong, 2015). Some managerial approaches like Lean concepts should be adopted for overall management of BIM (Arayici, et al., 2011). The synergy between Lean Construction and BIM has been realized through practice and research as well as the benefits brought by implementing both of them together (Dave et al., 2011). Some of these benefits can summarized in the following points:

- Waste reduction in the design phase due to enhanced communication between different disciplines and the client in addition to the improved quality and accuracy of drawings and documentation, and during construction by linking design information with cost estimate, budget and schedule, in addition to the synchronization of information of management system.
- Early identification of value from client's perspective thanks to the visualization of the final product. The client is able to approve or disapprove the design.
- Easier identification of value-generating processes and avoiding non-value adding processes.
- Enhanced interoperability and process transparency: the high level of visualization develops a common understanding among project team, facilitates communication

and data sharing between all disciplines as updates and changes in design or plans are seen by all team members.

- Reducing cycle time during construction due to the optimized operational schedules and less conflicts.

2.7.3 LeanBIM and sustainability

The following mutual impact matrix between Lean Construction, BIM and sustainability has been introduced by (Koskela et al., 2010):

Table 2.4: Lean-BIM-Sustainability mutual impact matrix (Koskela et al., 2010)

	IMPACTS ON DIFFERENT DRIVERS		
Impacting driver	BIM	Lean Construction	Sustainability
BIM	-	Enables waste reduction and value creation in tens of ways, such as coherent design information, clash detection, visualization and evaluation of proposed design solutions, etc.	Enables sustainability evaluation of proposed solutions, for example simulations of energy consumption and CO_2 footprint.
Lean Construction	Facilitates the implementation of BIM through systematic approach; adds the necessary integrating process layer; and specifically requires collaboration between the parties.	-	Achieves higher resource efficiency through reduced waste. Leads to reduction of harmful emissions through higher operational and product reliability. Facilitates the achievement of sustainability targets through emphasis on value generation.
Sustainability	Reinforces the use of BIM through the need for complex analysis and simulations.	Reinforces Lean efforts through partial alignment of purposes and methods.	-

Chapter 3

RESEARCH METHODOLOGY

3.1 General

To achieve the conclusions of this research, qualitative and quantitative analysis have been applied. The methodology followed will be presented through this chapter.

3.2 Qualitative analysis and deductive approach

An in depth study of Lean concept and BIM from various resources is conducted, data has been collected from various resources related to Lean, BIM and sustainability such as papers and articles from internet and scientific journals, publications and books. To understand in depth the different types of waste in construction and its causes, Lean philosophy and benefits of its implementation alongside with BIM. To ensure the accuracy of the research results, choosing up-to-date and relevant materials were taken into consideration while preparing this study. The research covered multiple areas such as:

- Waste in construction.
- History of Lean production and Lean Construction.
- The main differences between Lean and traditional construction management methodologies.
- Overview on BIM, its applications and benefits.
- The relationship between Lean Construction and BIM.
- Benefits of implementing BIM alongside with Lean in the construction industry.

3.3 Quantitative analysis and inductive approach

A survey has been conducted to collect data from researchers and industry professionals. The questionnaire is created online using google forms[1], and consisted of 22 close-ended questions structured to investigate the perception of industry professionals and researchers with regards to the reduction of different types of waste in different construction processes, factors affecting sustainability and LeanBIM implementation. Furthermore, the respondents were not asked to disclose their identity to encourage the credibility of the collected information.

3.3.1 Questionnaire design

The key purpose of the survey is to identify the Lean professionals and researchers' point of view regarding implementing BIM along with Lean concepts in the construction industry and the impact of its implementation on the resources efficiency and sustainability. The questionnaire is consisting of 22 close-ended questions, broken-down into three parts A, B and C:

- Part (A) is structured to investigate general information about respondents and their experience (7 questions).
- Part (B) is structured to identify the major causes of waste and resource consuming activities in construction and factors that affect the sustainability of buildings (7 questions).

[1] A free online service from Google which allow the users to create surveys and collect data.

- Part (C) is structured to examine the ability of embracing both Lean and BIM concepts within the industry, the impact of its implementation and challenges affect the implementation (8 questions).

3.3.2 Target respondents

Due to the nature of the research subject and to identify the respondents, a purposive sampling technique is applied in the selection of the respondents for the survey. The author used online professional network LinkedIn[2] to identify professionals and researchers in the areas of Lean Construction and BIM from all over the world, contacted them personally and sent them the survey link. In addition to personally approaching the respondents, posts with the survey link have been posted in Lean Construction institute official LinkedIn group and other professional Lean Construction and BIM groups.

3.3.3 Data Collection

Out of sixty-three (63) invitation to complete the survey sent Fifty-one (50) were accepted and completed. Which brought the response rate to 79.4% which is adequate for construction industry (Newman et al, 2002).

3.3.4 Method of data analysis

Part A questions were analyzed by representing the percentage and frequency of answers using pie and bar charts. Questions of parts B and C were analyzed using mean score value in which numerical or ordinal values are replaced by assigned ranks

[2] A professional networking website: www.linkedin.com

started from 1 then 2, 3, and so on till the highest rank. The mean value of answers and relativity importance index (RII) are calculated to rank this factor among other factors.

Mean value = $\frac{Ranking\ x\ number\ who\ choose\ the\ ranking}{Total\ number\ of\ respondents}$

RII = $\frac{Mean\ value}{maximum\ point\ on\ the\ likert\ scale}$

According to Mbamali (2002), RII values are interpreted as;

RII < 0.06: Implies Item has low rating.

0.06 ≤ RII ≤ 0.80: Implies item has high rating.

RII ≥ 0.80: implies item has very high rating.

Chapter 4

RESULTS AND DISCUSSION

4.1 General

This chapter presents and discuss the survey results. The survey link was sent directly to 67 Lean/BIM professionals as well as Lean Construction Institute group on LinkedIn. 50 respondents have successfully completed the survey. Respondents were required to answer all the questions.

4.2 Part A - Respondents' profiles

The respondents were asked to provide their country, academic background, field of work, total years of professional experience and experience with Lean Construction and BIM. The respondents who completed the questionnaire were from Argentina, Australia, Brazil, Egypt, France, Hong Kong, India, Ireland, Italy, Lebanon, New Zealand, Nigeria, Peru, Qatar, UK and USA.

Figure 4.1 shows the distribution of respondents' academic backgrounds.

- 42% are MSc degree holders.
- 40% are BSc degree holders.
- 6% are MBA degree holders.
- 4% are PhD degree holders.
- 6% are holders of other degrees.

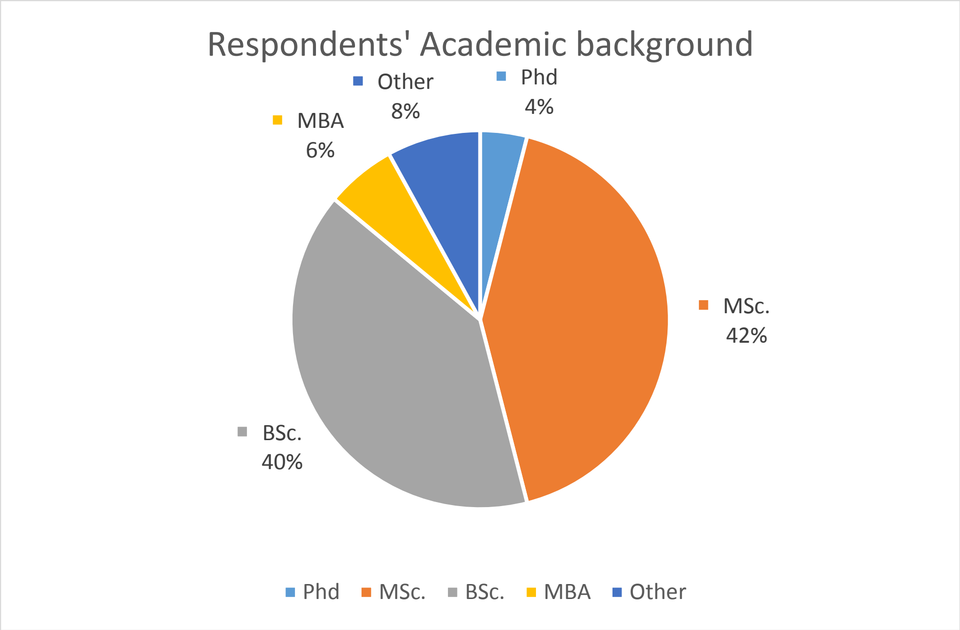

Figure 4.1: Respondents academic background

The respondents' disciplines are;

- 52% are working in project management positions.
- 8% are researchers and university staff.
- 8% are site engineers and supervisors.
- 32% are from other disciplines.

Figure 4.2 shows the distribution of respondents' disciplines.

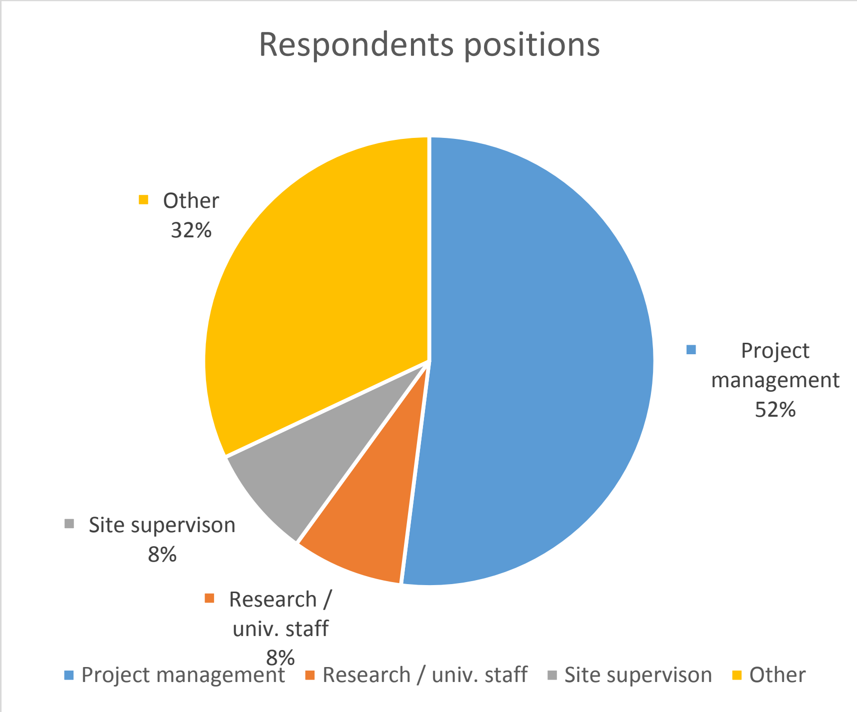

Figure 4.2: Respondents' Positions

As shown in Figure 4.3, respondents’ sector are;

- 40% of respondents are working in contracting companies.
- 32% are working in consulting companies.
- 12% are working in educational institutes.
- 16% are working in other sectors

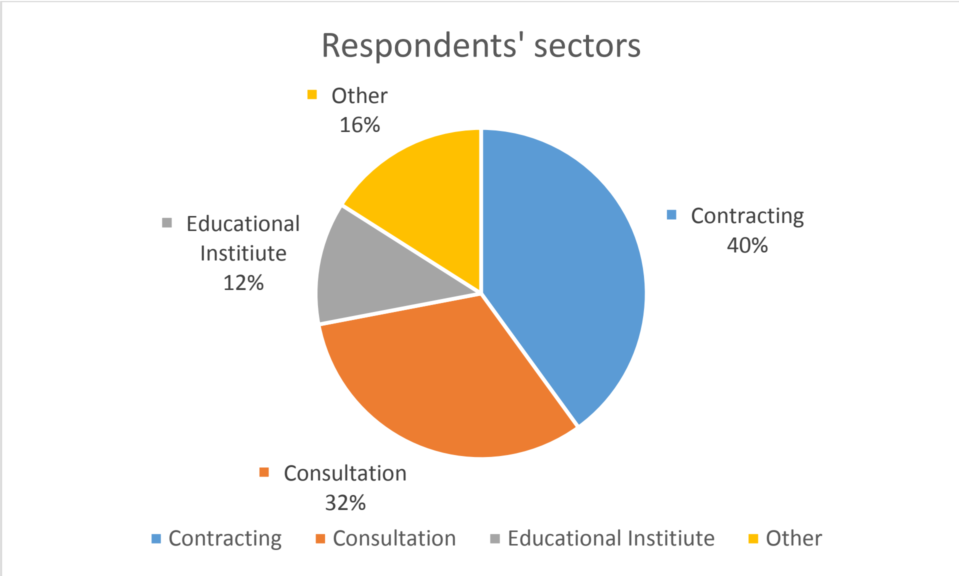

Figure 4.3: Respondents' Sectors

Figure 4.4, 4.5, 4.6 show the total professional years of experience, Lean Construction experience and BIM experience respectively.

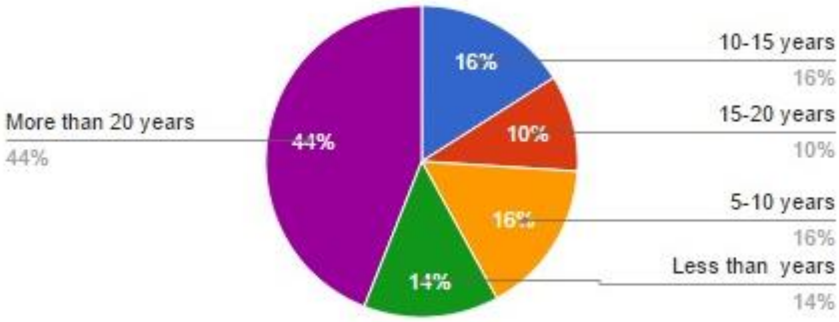

Figure 4.4: Years of experience within the construction industry

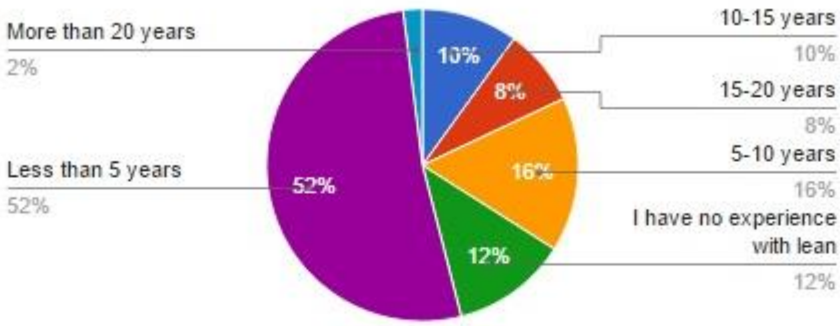

Figure 4.5: Years of Lean Construction experience

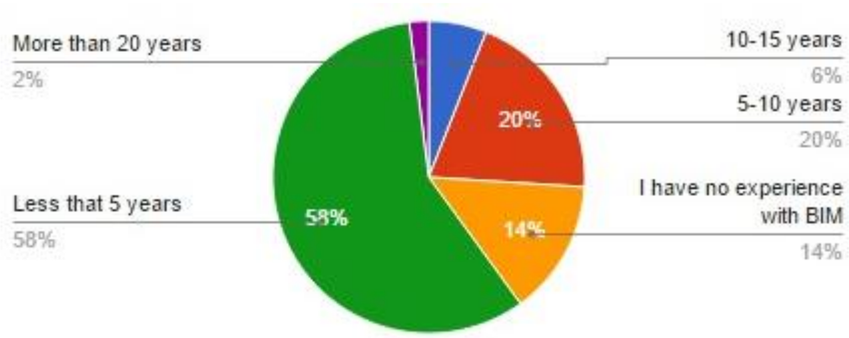

Figure 4.6: Years of BIM experience

4.3 Part B – Causes of waste and factors affecting sustainability

In the beginning of this part respondents were asked to rate on a scale of 5 how construction is a waste producing industry where 1 means strongly disagree, while 5 means strongly agree. The respondents agreed to a high degree that construction is a waste generating industry. As shown in Figure 4.7, the average rate was 4.36.

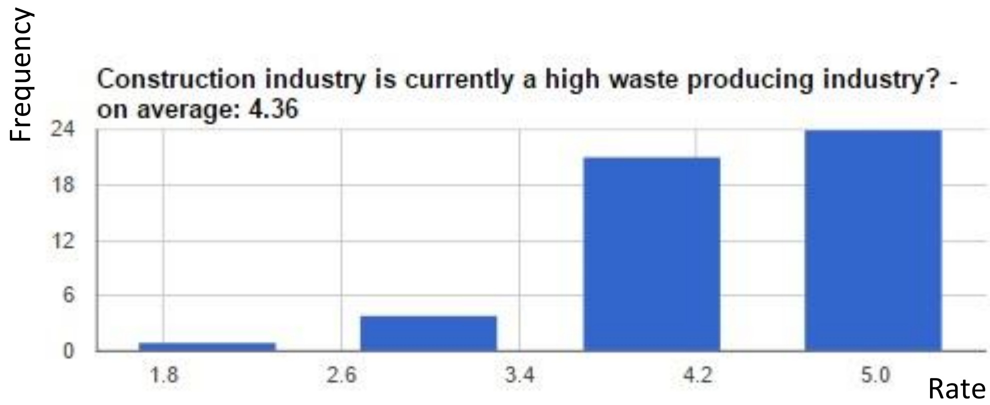

Figure 4.7: Waste producing rating of construction industry

4.3.1 Factors affecting resource consumption

Respondents were asked to rate on scale of 4 (where 1 means has no effect, and 4 means has a big effect). The effect of 12 factors listed in table 4.1 on the resource consumption. The results showed that poor communication between different disciplines, correction or defects and waiting time between activities were the most affecting factors.

Table 4.1: Factors affecting resource consumption

	N	Mean	RII.
Poor communication between different disciplines	50	3.7	0.925
Correction or defects	50	3.56	0.89
Waiting time between activities / Idle time	50	3.46	0.865
Unnecessary movements of workers and equipment in the work site	50	3.38	0.845
Lack of management	50	3.34	0.835
Underutilized people	50	3.28	0.82
Transportation of material	50	3.26	0.815
Processing and over processing	50	3.04	0.76
Over production	50	2.92	0.73
Skill level of the workers	50	2.84	0.71
Safety in workplace	50	2.84	0.71
Inventories	50	2.78	0.695

To achieve resource efficiency, respondents were required to rate on a scale of 5 the importance of the factors listed in table 4.2 (where 1 is extremely not important, and 5 is extremely important). The results showed that interoperability, involvement of clients in design stage, proper scheduling, assessment of design changes' impacts on the final product and product visualization were the top affecting factors.

Table 4.2: Factors affecting resource efficiency

	N	Mean	RII
Interoperability and communication between different disciplines	50	4.42	0.884
involvement of the client in the design stage	50	4.32	0.864
Proper scheduling and planning	50	4.24	0.848
Assessment of the design changes' impacts in the final products	50	4.06	0.812
Visualization of the final product (3D, 4D ...)	50	4	0.8
Virtual prototype and simulation	50	3.88	0.776
Safety in work place	50	3.88	0.776
Automatic generation of shop drawings	50	3.46	0.692
Automatic testing for the final products against codes and specs	50	3.32	0.664

4.3.2 Waste reduction

Respondents were asked to rate the effectiveness of the factors listed in table 4.3 on reducing waste in construction, on scale of 4 where 1 means no effect and 4 means high effect. Embracing new project management paradigm like Lean Construction was the most effective factor, sharing ideas between employees on how to reduce waste and using new tools like BIM were in the second and third place respectively. It was noted also that the governmental decisions or actions has a low effect on waste reduction.

Table 4.3: Factors affecting waste reduction

	N	**Mean**	**RII**
Embracing of new project management paradigm like Lean Construction	50	3.5	0.875
Ideas sharing between employees on how to reduce waste	50	3.48	0.87
Employing new tools and techniques like BIM	50	3.34	0.835
Increasing the awareness within the industry	50	3.2	0.8
Government decisions / actions	50	2.3	0.575

4.3.3 Sustainability

Respondents were asked to rate on a scale of 4, where 1 means no effect and 4 means high effect, the effectiveness of factors listed in tables 4.4, 4.5 and 4.6 on sustainable design. The factors effect were measured on the three main aspects of sustainable design (Energy, water and material conversion, lifecycle and humane design). Figure 4.8 shows the effect of these factors on sustainable design.

Table 4.4: Factors affecting Energy, Water and Material conversion

	N	**Mean**	**RII**
Design of buildings	50	3.48	0.87
Construction materials	50	3.18	0.795
Building schedules / planning	50	3	0.75
Product visualization (3D, 4D, ..)	50	3	0.75
Arrangement of work site	50	2.98	0.745
Conformity with codes and standards	50	2.84	0.71

Table 4.5: Factors affecting life cycle design

	N	**Mean**	**RII**
Design of buildings	50	3.6	0.9
Construction materials	50	3.18	0.795
Building schedules / planning	50	3.08	0.77
Product visualization (3D, 4D, ..)	50	3.04	0.76
Conformity with codes and standards	50	2.82	0.705
Arrangement of work site	50	2.7	0.675

Table 4.6: Factors affecting humane design

	N	**Mean**	**RII**
Design of buildings	50	3.3	0.825
Construction materials	50	2.82	0.705
Product visualization (3D, 4D, ..)	50	2.74	0.685
Building schedules / planning	50	2.56	0.64
Arrangement of work site	50	2.52	0.63
Conformity with codes and standards	50	2.42	0.605

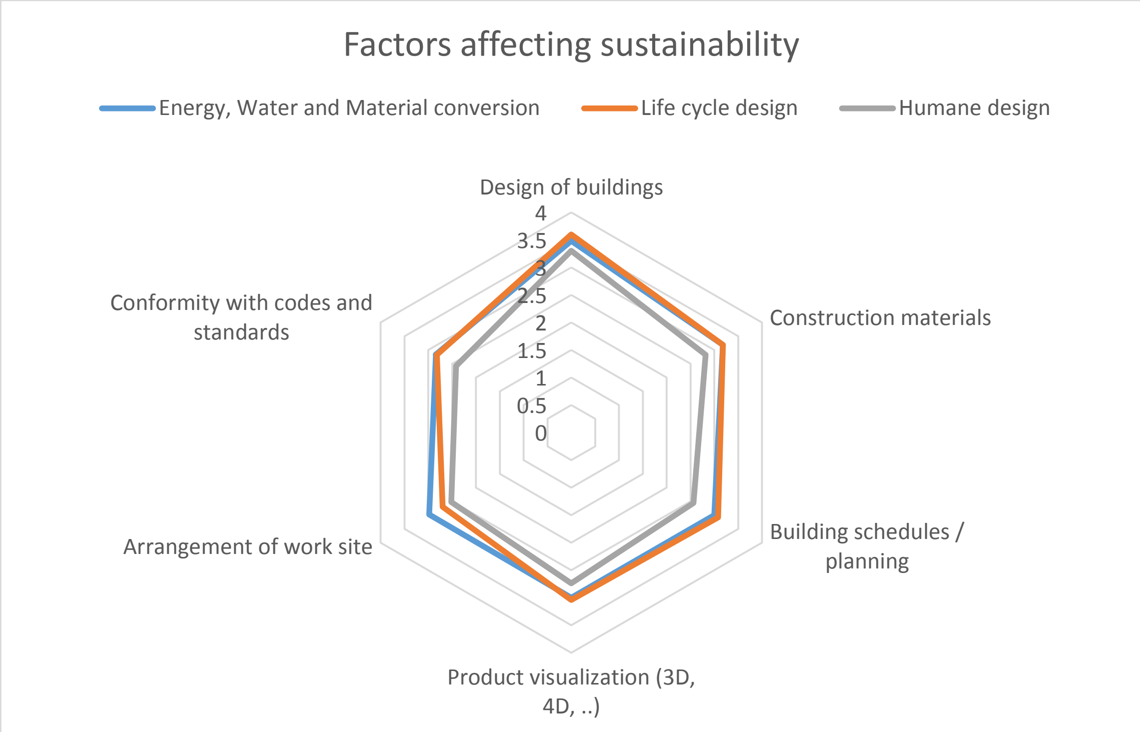

Figure 4.8: Factors affecting sustainability

Design of building and construction materials were the top factors affecting sustainability of building, while planning and scheduling were in the next place for their effect on energy, water and material conversion and lifecycle design. It was noted also the visualization of the final product is the next place for its effect on humane design.

4.4 Part C – Embracing of LeanBIM concept

4.4.1 Perspective about Lean Construction and BIM

Respondents' perspective about Lean Construction and BIM was measured on a scale of 5 where 1 means strongly disagree and 5 means strongly agree. Respondents agreed that BIM implementation is expensive, while they didn't agree that Lean Construction implementation is easy, they agreed that Lean implementation is easy for organizations that already implement BIM. Figure 4.9 shows how respondents agreed and disagreed to the factors listed in table 4.7

Table 4.7: Professionals' perspective about Lean and BIM

	N	Mean	Std. Dev.
BIM implementation is expensive	50	3.48	0.922
Lean implementation is easy for organizations that already implement BIM	50	3.1	1.044
BIM implementation is easy	50	2.52	0.943
Lean implementation is expensive for organizations that already implement BIM	50	2.42	0.961
Lean implementation is expensive	50	2.36	0.889
Lean implementation is easy	50	2.28	0.96

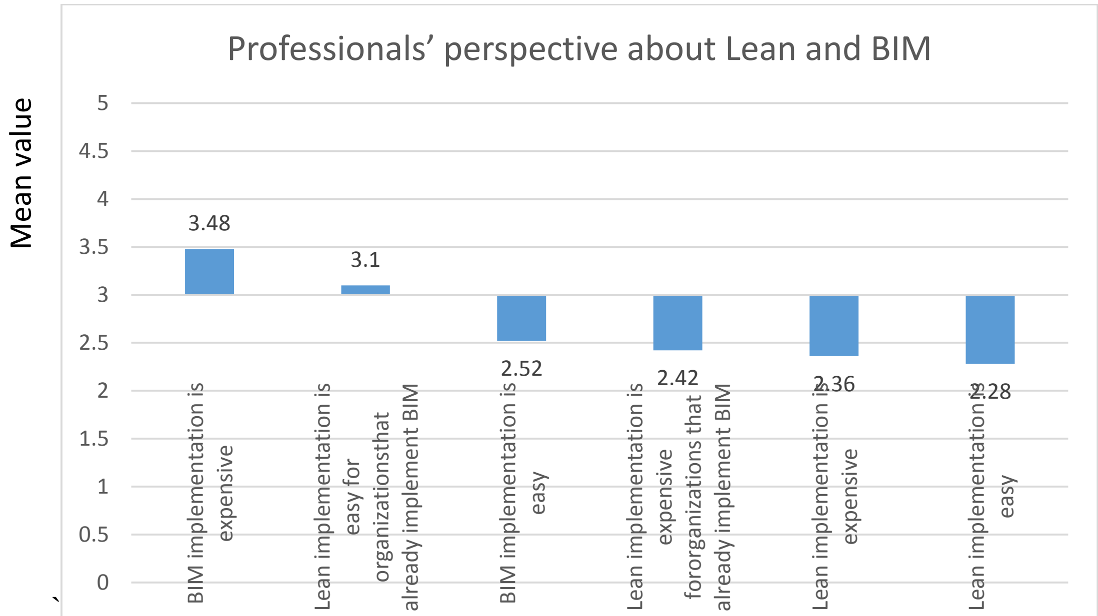

Figure 4.9: Professionals' perspective about Lean and BIM

4.4.2 Implementing of Lean Construction

The respondents were asked to rank on scale of 5, where 1 means extremely easy and 5 means extremely hard, how easy is implementing Lean with regard to the factors listed in Table 4.8 and 4.9. Culture within the construction industry was the most difficult factors against Lean implementation, however organizations that already implementing BIM expected to reduce the hardness of this factor, as well as reduction in time required to implement Lean concepts and training and hire new staff. While cost of implementation seemed to be an easy factor, it was noticed that the cost of Lean implementation will be decreased for organizations that already implement BIM.

As shown in Figure 4.6, respondents agreed that difficulty of all factors should be decreased when implementing of Lean within an organization which is already implementing BIM.

Table 4.8: Difficulty of Lean implementation

	N	**Mean**	**RII**
Culture within the construction industry	50	4.28	0.856
Collaboration between design, MEP and structural engineers	50	3.64	0.728
Time required to implement	50	3.6	0.72
Training and hire new staff	50	3.58	0.716
Cost of implementation	50	2.94	0.588

Table 4.9: Difficulty of Lean implementation with BIM

	N	**Mean**	**RII**
Culture within the construction industry	50	3.46	0.692
Time required to implement	50	3.02	0.604
Training and hire new staff	50	3	0.6
Collaboration between design, MEP and structural engineers	50	3	0.6
Cost of implementation	50	2.62	0.524

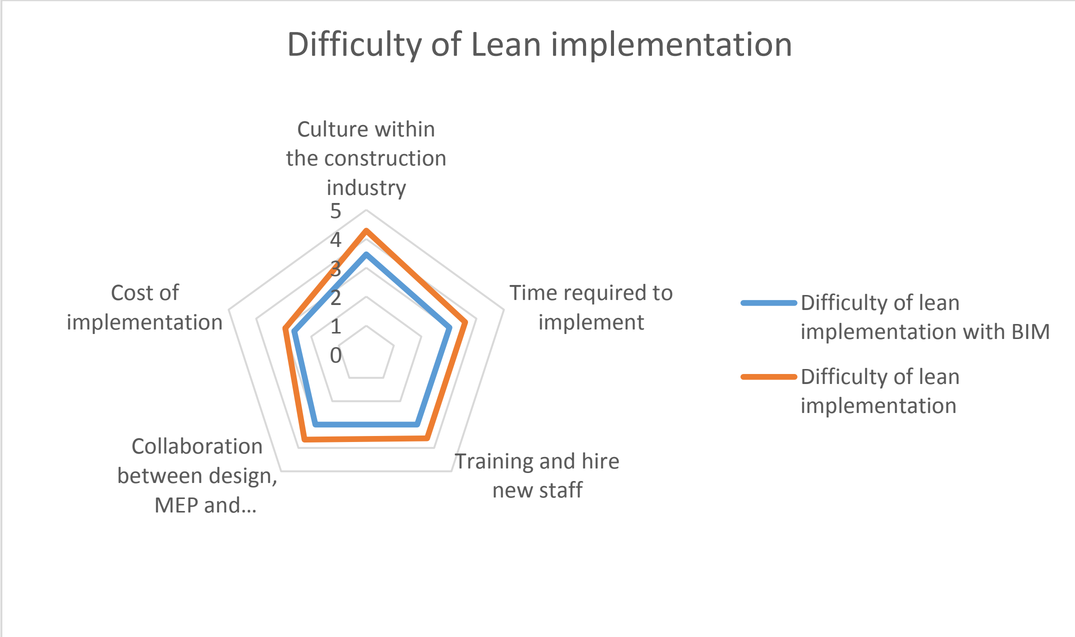

Figure 4.10: Difficulty of Lean implementation

4.4.3 BIM benefits to Lean

Respondents were requested to rate the benefits of BIM to Lean on a scale of 4, where 1 means has no effect and 4 means high effect. Respondents agreed that BIM is highly benefits to Lean in the facilitating the collaboration between different disciplines, enabling visualization and reducing of time and cost required to implement Lean Construction.

Table 4.10: BIM benefits to Lean

	N	Mean	RII
Facilitating the collaboration between different disciplines	50	3.68	0.92
Enabling visualization of the final product	50	3.56	0.89
Reduce the time required to implement Lean	50	3.04	0.76

4.4.4 The effect of contribution of different sectors on LeanBIM implementation

The influence of different sectors on implementation of LeanBIM were measured on scale of 4, where 1 means no influence and 4 means mandatory to embrace the concept.

The results showed that owners and contractors are the most influencing sectors, while government seem to have the lowest effect on implementing of LeanBIM concepts.

Table 4.11: The effect of contribution of different sectors on LeanBIM implementation

	N	Mean	RII
Owners (real estate developers, investors, governments, ...etc)	50	3.04	0.76
Contractors	50	3.04	0.76
Design firms	50	2.82	0.705
Consultants	50	2.82	0.705
Educational institutes	50	2.72	0.68
Professional bodies / societies	50	2.72	0.68
Government (laws and regulations)	50	2.46	0.615

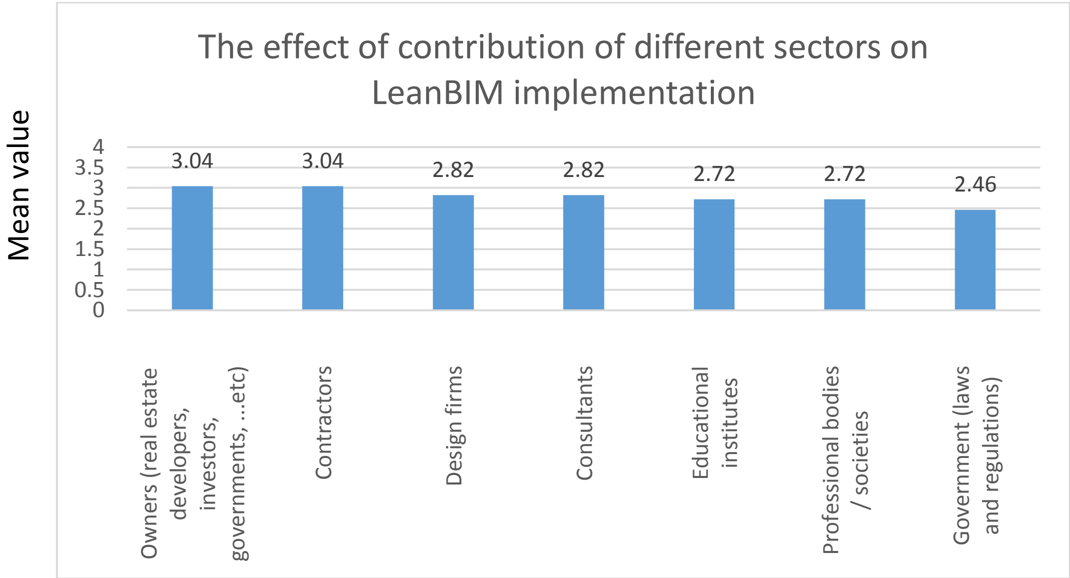

Figure 4.11: The effect of contribution of different sectors on LeanBIM implementation

4.4.5 Challenges facing LeanBIM implementation

Respondents were asked to rate on a scale of 5, where 1 means very low and 5 means very high, the challenges facing LeanBIM implementation. It was noted that the industry need is currently the biggest challenge followed by the shortage of professionals in the field of Lean Construction and BIM. It seems also that there is a lack of legal framework that support collaboration between all parties in addition to the low awareness about LeanBIM and its benefits to the industry. It was also noted that the governmental support is not a hard challenge against LeanBIM implementation.

Table 4.12: LeanBIM Challenges

	N	Mean	RII
The industry need for improved construction management concepts	50	4	0.8
Availability of professionals in the field	50	3.8	0.76
Availability of legal framework that support collaboration (i.e. types of contract)	50	3.78	0.756
Awareness of LeanBIM benefits to the industry	50	3.46	0.692
Investment in IT infrastructure	50	3.38	0.676
Governmental support (laws and regulations)	50	2.96	0.592

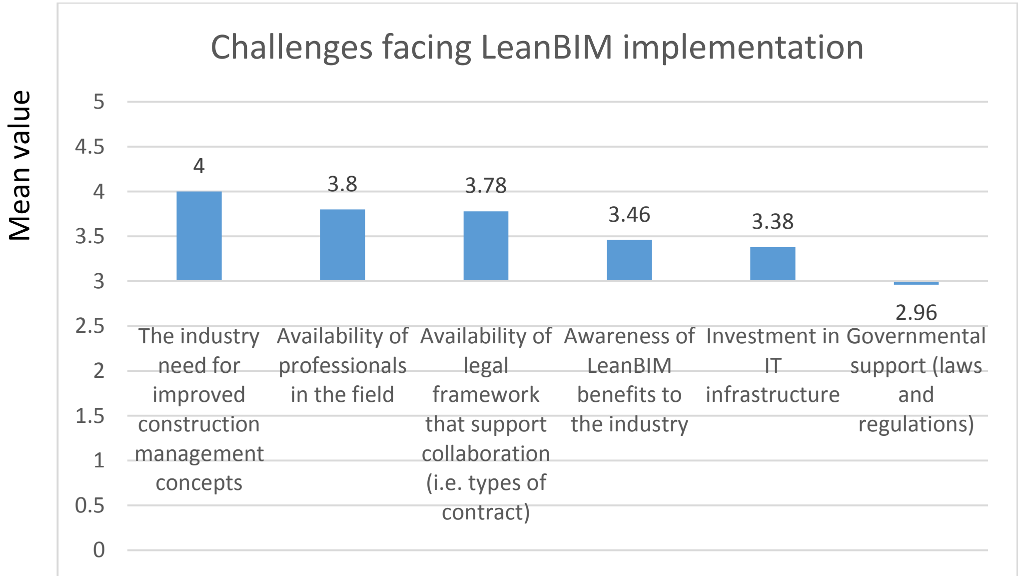

Figure 4.12: Challenges facing LeanBIM implementation

4.4.6 Perspectives about LeanBIM

The respondents perspective about LeanBIM were measured by rating the factors listed in table 4.13 about LeanBIM on a scale of 5, where 1 means strongly disagree and 5 means strongly agree. Respondents agreed that LeanBIM implementation saves money and time, and it is required for today and future needs. They agreed also that it help reducing the negative environmental impacts of construction. It was also noted that respondents have disagreed that LeanBIM can only implemented in strong economies or by big companies.

Table 4.13: Perspectives about LeanBIM

	N	**Mean**	**Std. Dev.**
Saves time	50	4.56	0.637
Saves money	50	4.4	0.825
Is required for today's need	50	4.3	0.755
Is recommended for the future needs	50	4.24	1.05
Reduces the negative environmental impacts of the construction	50	4.04	0.799
Will be mandatory in the future	50	3.94	0.988
Is hard to be implemented	50	3.28	1.132
Must be compulsory by governments	50	3.08	1.383
Requires governmental actions (laws and regulations)	50	2.7	1.487
Seems to be too early to be implemented	50	2.4	1.249
Is not required for small and mid-size projects	50	2.08	0.977
Can be applied ONLY in strong economies	50	2.02	1.122
Can be applied ONLY by big companies	50	1.96	0.999

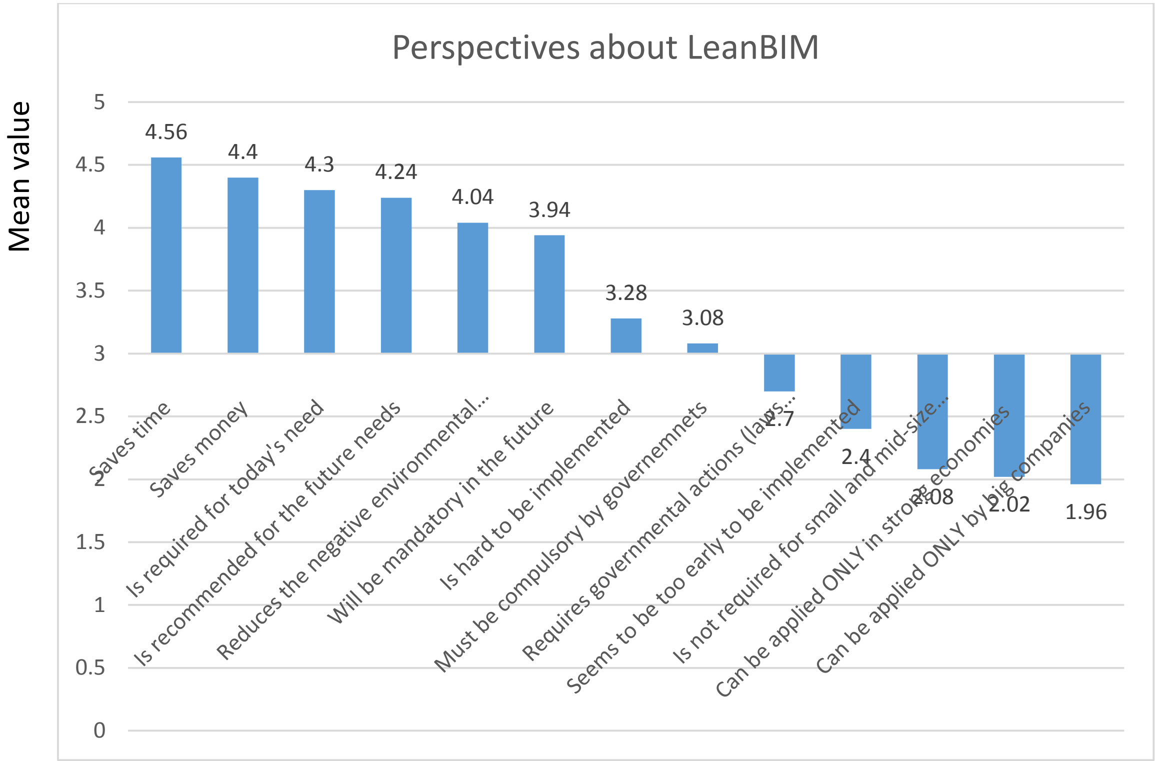

Figure 4.13: Perspectives about LeanBIM

4.4.7 Effects of LeanBIM on final product

Respondents were asked to rate on a scale of 5, where 1 is extremely reduce and 5 is extremely increase, the effect of LeanBIM concept implementation on the final product according the factors listed in table 4.14. It was noted that implementing of LeanBIM concept increase the overall quality of the final product and increase safety in the work place while decreasing the resource usage and final product cost as well the negative environmental impacts during and after the construction process.

Table 4.14: LeanBIM effect on final product

	N	**Mean**	**Std. Dev.**
Overall quality	50	3.62	1.278
Safety in the work place	50	3.48	1.403
Resources usage	50	2.48	1.204
Final product cost	50	2.1	0.781
Negative environmental impacts during construction	50	1.92	0.891
Delivery time	50	1.82	0.865
Negative environmental impacts after construction	50	1.74	0.729

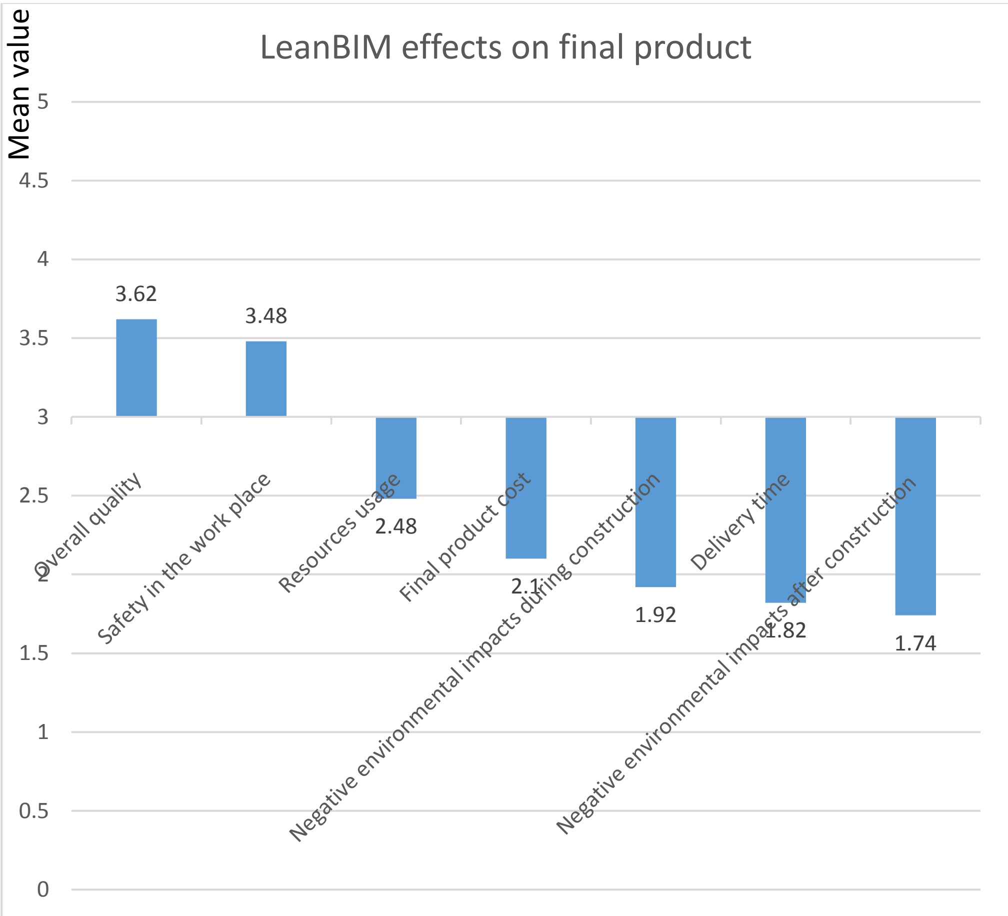

Figure 4.14: Effect of LeanBIM on final product

Figure 4.15 summarizes the effect of LeanBIM implementation on resource efficiency and sustainability. Implementing LeanBIM concept enables interoperability, client involvement in all construction stages, product visualization and assessment of design changes' impact on the final product which help for proper project management and higher safety in the workplace. These factors directly lead to resource efficiency. The high level of visualization and prototyping enabled by LeanBIM facilitates the design process and provides more control over their designs, it also helps in choosing the proper construction materials and arrangement of work at sites which help achieving sustainability in construction.

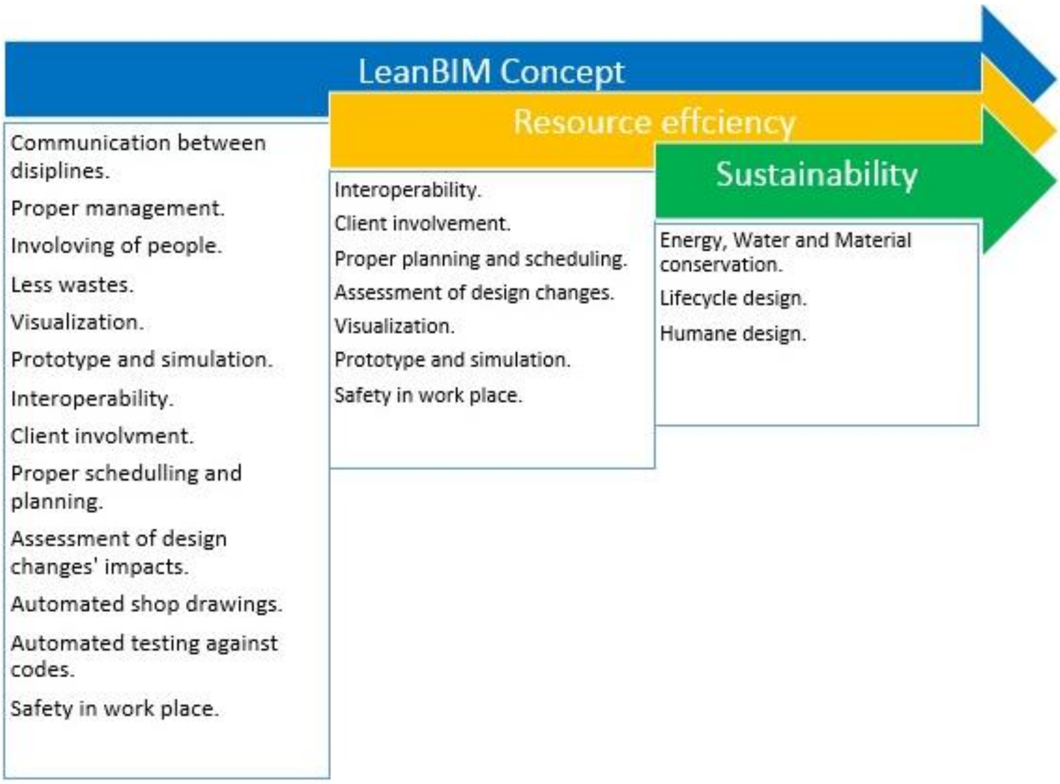

Figure 4.15: LeanBIM, Resource efficiency and sustainability framework

4.5 Limitations

The number of respondents is 50 which considered the main limitation to this research, Also the respondents came from various countries and sectors which may not reflect the real challenges and opportunities for each country or sector aside.

The research is focusing on the effect of LeanBIM on sustainability and resource efficiency and so it is not covering all benefits that LeanBIM can bring to the industry.

Chapter 5

CONCLUSION AND RECOMENDATIONS

5.1 General

The purpose of this research was to investigate the economic and environmental benefits of implementing LeanBIM concepts in the construction industry as well as the challenges facing its implementation.

5.2 Conclusion

5.2.1 Lean and BIM Synergy

Unlike Lean, BIM implementation is expensive, however, it facilitates Lean implementation though;

- Reducing the cost of Lean implementation.
- Reducing time required for Lean implementation.
- Changing the culture within the organization to accept and understand Lean concepts.
- Facilitates collaboration between different disciplines.
- Facilitates training and hiring of new staff.

5.2.2 Implementing of LeanBIM

Implementing of LeanBIM saves time and money, reduces the negative environmental impacts and it's required for both today and future needs as it. In spite of hardness of implementation, it is expected to be mandatory in the future.

Owners and contracting firms are the most influencing sectors on embracing of LeanBIM, while design firms, consultants, educational institutes, professional bodies and governments are coming in the second place.

5.2.3 Benefits of LeanBIM

5.2.3.1 LeanBIM and resource efficiency

LeanBIM helps achieving higher resource efficiency through;

- Reducing waste during, before and after construction.
- Enabling interoperability and collaboration between all disciplines.
- Enabling client involvement in the design stage and throughout the project.
- Proper scheduling and planning.
- Assessment of design changes' impacts on the final products.

5.2.3.2 LeanBIM and sustainability

LeanBIM improves designing and prototyping process through the high level of visualization which is considered the most effective factor on sustainability of buildings.

- Waste reduction and higher resource efficiency.
- Proper planning and scheduling.
- Facilitates achieving sustainability targets by focusing on value generation.

- LeanBIM enables sustainability evaluation for example simulations of energy consumption.
- Sustainability targets reinforces the implementation of LeanBIM through the need for complex simulation and analysis.

5.2.4 Challenges

It seems that there is a shortage in LeanBIM professionals, plus a lack of legal framework and contract system that enable collaboration between all parties. The awareness of LeanBIM is still not common within the industry. In addition to the huge initial investment in IT infrastructure required for implementing BIM.

5.3 Recommendations

Awareness should be increased among the industry professionals specially owners and contracting firms about the importance of embracing new concepts within the industry to minimize the negative environmental impacts and maximize the economic benefits.

In order to enable collaboration between all parties, a new forms of legal framework and contracts should be developed.

Educational institutes should provide programs about new construction management concepts that help to prepare a new generation of professionals who are ready to implement these concepts on the ground.

5.4 Recommendations for further research

This study recognizes that further research is required in order to better identify the benefits and challenges of implementing LeanBIM concepts. The following areas are recommended for more research:

- Investigation of LeanBIM challenges in each country aside.
- Further researches should be required to investigate in depth the role of educational institutes and professional bodies in preparing a Lean/BIM professionals.
- Research needed to be carried out on projects owners (real-estate developers, investors and governments) the results may be helpful in identifying the key challenges against LeanBIM implementations.

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APPENDICES

Appendix A: Introduction Letter

Thank you for completing this survey.

The following questionnaire is a part of my master thesis research about implementing of LeanBIM concepts in the construction industry. The questionnaire is structured to research the perceptions of industry professionals and researchers with regards to the reduction of different types of construction wastes by implementation of LeanBIM concepts.

The questionnaire can be complete online, and should only take few minutes of your time. I would be very grateful if you could complete within one working week.

Needless to say all information provided will be treated with strict confidence and will be used for research purpose only.

For any information or assistance please feel free to contact me.

Thanks in advance

Moataz Younes

moatazyounes@gmail.com

Appendix B: Survey Questions

Section (A)

General information and professional experience

Where are you from?

Please write your country

[ ]

Highest education level

- ( ) Phd
- ( ) MSc.
- ( ) Bsc.
- ( ) Autre :

To which sector your organization belongs?

- ( ) Contracting
- ( ) Consultation
- ( ) Educational Institute
- ( ) Professional body
- ( ) Autre :

What best describes your position?

- ( ) Researcher / University staff
- ( ) Architect
- ( ) Site Engineering / Supervision
- ( ) Structural design
- ( ) Project Management
- ( ) Autre :

Years of experience within the construction industry

- Less than years
- 5-10 years
- 10-15 years
- 15-20 years
- More than 20 years

Years of Experience with lean construction

- I have no experience with lean
- Less than 5 years
- 5-10 years
- 10-15 years
- 15-20 years
- More than 20 years

Years of Experience with BIM

- I have no experience with BIM
- Less that 5 years
- 5-10 years
- 10-15 years
- 15-20 years
- More than 20 years

Section (B)

Causes of waste in construction, resource consuming activities and factors affecting sustainability.

Construction industry is currently a high waste producing industry?

	1	2	3	4	5	
I Don't agree at all						I Strongly Agree

What is the effect of the following on resources consumption

	Has no effect	Small effect	Moderate	Big effect
Waiting time between activities / Idle time				
Unnecessary movements of workers and equipments in the work site				
Transportation of material (material movement in site that don't support the production process due to (road conditions, excessive handling, inadequate equipments...)				
Processing and over processing (the nature of process, i.e. plastering a ceiling will cause waste of mortar)				
Inventories (inventories exceeding the production requirements)				
Over production (production is more, faster than, or before it is				

needed)				
Correction or defects (when the final product doesn't meet the quality specs)				
Underutilized people (not making use of people creativity, mental and physical abilities)				
Poor communication between different disciplines				
Skill level of the worker				
Safety in workplace				
Lack of management				

How effective is the following actions / solutions in reducing waste in construction industry?

	Not effective	low	moderate	high
Government decisions / actions				
Embracing of new project management paradigm like lean construction				
Employing new tools and techniques like BIM				
Increasing the awareness within the industry				
Ideas sharing between employees on how to reduce waste				

How do you rate the effect of the following factors on Energy, Water and Material conversion (Reduction, Ruse and Recycle)

	no effect	low	moderate	high
Design of buildings				
Building schedules / planning				
Construction materials				
Arrangement of work site				
Conformity with codes and standards				
Product visualization (3D, 4D, ..)				

How do you rate the effect of the following factors on life cycle design (prebuilding, building and post building phases)

	no effect	low	moderate	high
Design of buildings				
Building schedules / planning				
Construction materials				
Arrangement of work site				

Conformity with codes and standards				
Product visualization (3D, 4D, ..)				

How do you rate the effect of the following factors on humane design (interaction between humans and the natural world)

	no effect	low	moderate	high
Design of buildings				
Building schedules / planning				
Construction materials				
Arrangement of work site				
Conformity with codes and standards				
Product visualization (3D, 4D, ..)				

I believe that the following tools will increase the resource efficiency in construction

	Extremely not important	Not important	Moderate	Important	Extremely important
Visualization of the final product (3D, 4D ...)					
Interoperability and communication between different disciplines					
involvement of the client in the design stage					
Automatic testing for the final products against codes and specs					
Virtual prototype and simulation					
Assessment of the design changes' impacts in the final products					
Automatic generation of shop drawings					
Safety in work place					
Proper scheduling and planning					

Section (C)

Embracing of LeanBIM Concept withing the construction industry

How do you agree or disagree with the following

	Strongly disagree	Disagree	Moderate (not agree or disagree)	Agree	Strongly Agree
Lean implementation is expensive					
Lean implementation is					

easy					
BIM implementation is expensive					
BIM implementation is easy					
Lean implementation is easy for organizations that already implement BIM					
Lean implementation is expensive for organizations that already implement BIM					

How easy is implementation of Lean construction concepts regarding to the following items

	Extremely easy	Easy	Moderate	Hard	Extremely Hard
Cost of implementation					
Time required to implement					
Training and hire new staff					
Collaboration between design, MEP and structural engineers					
Culture within the construction industry					

How easy is it to implement lean construction cocepts in an organization already using BIM concepts

	Extremely easy	Easy	Moderate	Hard	Extremely Hard
Cost of implementation					
Time required to implement					
Training and hire new staff					
Collaboration between design, MEP and structural engineers					
Culture within the construction industry					

In your opinion, how influencing is the contribution of the following sectors in embracing the LeanBIM concepts

	has no influence	Has a small influence	has a significant influence	Mandatory to embrace the concepts
Government (laws and regulations)				
Owners (real estate developers, investors, governments, ...etc)				
Contractors				
Design firms				

Consultants	○	○	○	○
Educational institutes	○	○	○	○
Professional bodies / societies	○	○	○	○

How can you rate the current challenges facing the implementation of LeanBIM in the industry

	Very low challenge	Low challenge	Moderate (not low not high)	High challenge	Very high challenge
Governmental support (laws and regulations)	○	○	○	○	○
Awareness of LeanBIM benefits to the industry	○	○	○	○	○
Investment in IT infrastructure	○	○	○	○	○
Availability of professionals in the field	○	○	○	○	○
The industry need for improved construction management concepts	○	○	○	○	○
Availability of legal framework that support collaboration (i.e. types of contract)	○	○	○	○	○

In your opinion, Implementing of LeanBIM concepts ...

	Strongly disagree	Disagree	moderate	Agree	Strongly Agree
Saves money	○	○	○	○	○
Saves time	○	○	○	○	○
Reduces the negative environmental impacts of the construction	○	○	○	○	○
Is required for today's need	○	○	○	○	○
Seems to be too early to be implemented	○	○	○	○	○
Is recommended for the future needs	○	○	○	○	○
Will be mandatory in the future	○	○	○	○	○
Must be compulsory by governemnets	○	○	○	○	○
Is hard to be implemented	○	○	○	○	○
Is not required for small and mid-size projects	○	○	○	○	○
Can be applied ONLY in strong economies	○	○	○	○	○
Can be applied ONLY by big companies	○	○	○	○	○
Requires governmental actions (laws and regulations)	○	○	○	○	○

How can you rate the effect of the following BIM benefits in helping reaching lean construction goals?

	has no effect	low	mderate	high
Reduce the time required to implement lean				
Enabling visualization of the final product				
Facilitaing the collaboration between different desiplines				

How does implementing of LeanBIM concepts in a project affect the final product?

	Extremely reduce	Reduce	No effect	Increase	Extremely increase
Final product cost					
Delivery time					
Overall quality					
Safety in the work place					
Resources usage					
Negative environmental impacts during construction					
Negative environmental impacts after construction					

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