CHALMERS

Integrating BIM and Lean in the design phase

Investigating collocated design meetings (iRoom)

Master of Science Thesis in the Master's Programme Design and Construction Project Management

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Department of Civil and Environmental Engineering
Division of Construction Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2013
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ABSTRACT

The aim of this thesis is to study the possibility of integrating BIM (Building Information Modelling) and lean in the design phase of construction projects by focusing on iRoom design meetings. It has been argued that the average productivity of the construction industry is below the average of other non-farm industries, particularly manufacturing. It is believed that a reason for this low construction productivity can be lack of innovation in the construction industry since the main patterns of work in the construction have not been changed for many years. However, there are some innovative concepts, which are brought to the construction industry nowadays that aim at improving construction productivity. For instance, the visualization of workflow is one of these concepts that make the construction industry able to "try before build". The ability to "try before build" is proven to be beneficial for any industry since it helps to predict the waste before the execution phase. It is worth noting that by reducing waste, the productivity will increase, dramatically. BIM as a three dimensional (3D) modeling is the representative of visualization in the construction industry. However, these days many researchers try to combine cost and time as other BIM dimensions; known as 4D and 5D BIMs in the construction industry. Therefore, BIM is not only a way to visualize the construction sites before the execution phase but also a way to visualize the whole construction projects, including cost and time. Lean is another concept, which was firstly implemented by Toyota and then brought to construction by Koskela (1992). The main aim of Lean Construction is to focus on activities and minimize waste in all construction activities.

Although, a few cases are reported by scholars that intended to integrate BIM and Lean in the design phase of construction projects, the possibility of this integration has remained isolated. The aim of this research is to examine the possibility of integrating BIM and Lean in the design phase of construction projects. This study intended to focus only on the iRoom design meetings as a brilliant place to observe the possibility of the BIM-Lean integration. In order to examine this aim, firstly, a literature review was conducted to have enough knowledge of both concepts. In addition, since this study is a qualitative case study, interview-based research was chosen as the main source to examine the research aim. Six interviews were conducted via Skype with six employees of one of the biggest construction firms in Sweden. The interviews not only proved the possibility of integrating BIM and Lean, but also many advantages were found that are not explicitly mentioned in the literature before. For instance, easy collaboration, transparency and sharing of project knowledge between all stakeholders besides advantages of minimizing waste in the project were found for the BIM and Lean integration in the design phase of construction projects.

Keywords: BIM, Lean, Lean construction, Construction

Contents

Preface

This master thesis has been done as 30 credits of DCPM (Design and Construction Project Management) program in order to fulfil the requirement for getting my master degree at Chalmers University of Technology.

This study has been performed by Hashem Izadi Moud, with the help of my supervisor, Bosch-Sijtsema, and Ms. Tjell, PhD student in the division of construction management, department of Civil and Environmental Engineering, Chalmers University of Technology whom their help must be acknowledged. Also, I want to acknowledge the kind participation of six interviewees who I am not able to mention their names due to confidentiality issues. Moreover, I should thank my family who helped me a lot by their inspirational messages, letters and emails. I should also explicitly thank my father who inspires me by his motivational words whenever he thinks I need motivation.

Göteborg August 2013

Hashem Izadi Moud

1 Introduction

1.1 Background

It is well known that construction has not been as productive and innovative as other industries, compared to non-farm industries, particularly manufacturing. This has lead to many controversial debates among scholars during last two decades. Although there is no definite idea of what the reasons of this challenge are, and what could transfer construction to a more productive while sustainable industry, there are new ideas of how we can push the construction industry in a more productive way. Many scholars believe that unique nature of construction, like sensitivity to the environment and completely different requirements by different stakeholders in different projects, makes it extremely challenging to implement any generally accepted new method in order to improve it. However, it is believed that by adopting new technologies, like having computers and smart phones in construction sites, which are capable of modeling large architectures in 3D, the construction productivity can be improved (Li et al., 2008).

It is been always argued that the construction industry has lower productivity compare to the nonfarm industry; particularly manufacturing. The non-farm industry has the 10% incremental annual improvements during the last 40 years, though construction industry had a decline pattern for more than 40 years. This phenomenon may be explained by three unique conditions that happen only in construction and differ from any other industry (Li et al., 2008):

Firstly, the construction industry does not have any particular way or method to capture the knowledge which was generated in previous projects (Li et al., 2008).

Secondly, In contrast to the manufacturing industry, where there is always exists a fixed line for production, the construction industry does not have a fixed production line due to many different conditions. Also construction managers do not follow a simple method for establishing a production line. In addition, in manufacturing, the productivity is always increased by increasing in the speed of machinery, though the construction industry is more based on the people and their personal judgments and obviously, it is not easy to increase construction productivity which is based on personal judgment (Li et al., 2008).

Moreover, the construction industry has neither the ability nor the chance of simulating the working conditions before build. In other words, it has remained impossible for construction managers to "try before build" for many years. One of the main issues that hinder the chance of "try before build" in construction is the size of the construction projects. Most of the construction projects are too big and also expensive to be modeled in a lower scale. Moreover, most of the construction projects are unique in terms of budget, requirements, scope, size, participants etc. This uniqueness makes it even harder to "try before build" (Li et al., 2008).

In the beginning of the 21st century personal computers were produced that made anyone able to solve questions, which were not possible to solve before. Construction researchers decided to start modeling construction sites with computers during the planning phase. Moreover, researchers decided to use manufacturing industry

experiences in order to improve their ways of work. Koskela (1992; 2000) proposed an influential philosophy in construction, i.e., Lean philosophy, which originated from Toyota Company a few years earlier to improve efficiency and productivity, to construction. He named it Lean Construction (LC), which tries to eliminate waste and increase productivity. Since then, the construction industry struggles to develop new approaches, methods and software to make construction a leaner industry. However, there are some difficulties implementing Lean in the design phase because of difficulties in considering the effects of different actors, aspects and factors, which contribute in a construction project design phase. It is believed that one of the best ways of using all Lean potentials in construction projects is using 3D modeling software that helps architects, as well as all other partners, to model construction projects early in the design phase (Koskela, 1999; Schreyer et al., 2005; Li et al., 2008; Sacks et al., 2009; Sacks et al., 2010; Azhar, 2011).

Moreover, architects start using visualization software that tries to model construction projects before the construction phase starts. These software programs developed step by step in the industry. Nowadays this software is not only used for modeling construction projects but also for supporting construction managers to simulate whole construction projects by inserting time schedule and budget inside the primary model. The concept of modeling a construction project in the design phase is named BIM or Building Information Modelling. Although there are different definitions for BIM, the author of this thesis defines BIM as:

"Building Information Modelling (BIM) represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility."(Azhar et al., 2008).

There are only a few proposals and studies how to use BIM in order to implement Lean and make the design leaner (for instance, Sacks et al., 2009). Author found that there are not many research papers describing the ways it is possible to integrate BIM and Lean in the design phase. And more researches are needed in order to integrate the lean construction philosophy with BIM. Therefore, the idea of integrating BIM and Lean has the potential to be investigated more for future researches. By conducting a literature review, it becomes clear that BIM has primarily been applied in the construction design phase.

Some studies focus on combining the physical space, with particular methods to works as a design team in which BIM is integrated with Lean principles. These studies discuss the physical space, called the iRoom or Big Room. The iRoom is a physical space with an atmosphere, where all participants are able to present their knowledge/information in a way that this knowledge/information is easy to understand for other participants (Fox et al. 2000; Schreyer et al., 2005). This thesis tries to investigate iRoom design meetings and explore the advantages/disadvantages of BIM-Lean integration.

Therefore, studying how BIM and lean can complement each other in the design phase is chosen as my main research question in this thesis. More importantly, the study focuses in particularly, on the atmosphere, environment and the methods that implement in architecture firms to ease having a more collaborative atmosphere in order to design a leaner project while using BIM.

1.2 Aim

The aim of this research is to examine the possibility of integrating BIM and Lean in the design phase of construction projects by focusing on the iRoom experience.

1.2.1 Research question

The main research question of this research is:

How can Lean and BIM complement each other in the design phase?

However, there is a sub-research question, which its answer can be found by finding the answer of the main research questions:

In what aspects BIM and lean can complement each other in the design phase?

The author has tried to find answers to all of the mentioned questions; however it is always hard to generalize the findings of a thesis to the whole industry due to many different shortcomings that may exist in the research.

1.3 Structure of thesis

In the next sections (Chapters 2 and 3) the theoretical framework of Lean and BIM are discussed briefly. Integrating BIM and Lean as one of the main parts of this thesis is discussed on chapter four. The methodology will be discussed in chapter five. Chapter six summarizes the interview findings. Chapter seven presents a discussion part. Moreover, chapter eight presents a conclusion for this thesis.

2 Lean

4.1 Introduction

There are some special characteristics inherent in the heart of construction. A famous one is the separation between different phases in construction industry like separation between design and production that usually causes problems due to the future changes in design while production is already started. Many authors argue that design and production phase should be integrated in some ways in order to reduce the effects of this separation (Bröchner 1990; Koskela 2000; Anumba et al 2000). It is argued that lean philosophy has the potential to integrate design and construction phases (Jørgensen and Emmitt, 2009).

Outside of construction, it is proved that implementing lean production/manufacturing can be advantageous under some specific circumstances. Implementing a lean philosophy according to specific requirements of the industry and with dedicating effort for performance improvements can help organizations to adopt lean to their business. As soon as different organizations start to apply concepts like "lean" to their business by interpreting it in their ways; the concept tends to become decoupled from its basis. The concept may still exist with the same name but with a different interpretation, which is dedicated to any specific industry. Lean is one of those concepts which are interoperated by different businesses and industries, though there are some common elements that seem to exist in the core of it (Jørgensen and Emmitt, 2009):

- A focus on reducing unnecessary consumption/eliminating waste
- Applying end customer preferences in the early stages of the project to the end product
- Focus on production management and supply chain management from a customer perspective
- Focus on production management
- Focus on processes and flows of processes and materials (Jørgensen and Emmitt, 2009)

Applying a lean philosophy to the construction industry was inspired by Koskela in 1992. Later in 2000, he claimed that in spite of a long standing effort in improving production in construction; the construction industry suffers from lack in productivity for many years. Koskela proposed that the construction industry needs a general theory in order to focus on some basic elements to be able to improve. Although his effort was inspired by the Toyota lean strategy, Koskela's lean construction offers a different interpretation of Toyota and therefore varies in some of its principles. Koskela (1992; 2000) proposed three elements that should be focused on in construction: transformation, process and value. He emphasized that in construction the importance of process and value are underestimated, though construction focus only on transformation. However, Koskela's work has been cited many times, there

are only very few research papers on lean construction which discuss the whole lean philosophy in details. Since 1990s, the term "Lean" caught the attention in the industry. It has been debated as a "new understanding of the construction" by many scholars. However, one of the most important publications that provoked the awareness of Lean was "Rethinking Construction" Egan Report (DETR, 1998) that indicated that lean thinking should be implemented into construction in order to improve the performance and productivity (Jørgensen and Emmitt, 2009).

2.1 Lean definition

The definitions for "lean construction", "lean" and "lean design" are always ambiguous and equivocal. The construction management literatures usually refer to these concepts as something that is pre-defined and everyone knows it very well though in practice, there is a lack of common definition for these concepts. This phenomenon leads to unclear definitions and therefore, unclear discussions in the publications. Jørgensen and Emmitt (2009) discuss the issue of ambiguity in lean definition. They highlighted that lean definitions are usually implicit and based on references which finally referred to popular management books and literature like Womack et al. (1990) and Womack and Jones (1996) and none of the mentioned books provide a coherent and clear definition for lean terms. Ambiguity in lean definitions results in vague and variously different understandings of lean terms and techniques. Some scholars go even beyond this idea and proposed *"the meaning of lean construction is continuously renegotiated within localized contexts."* (Green and May, 2005; Jørgensen and Emmitt, 2009)

Lean design is another term, which is even less discussed compared to "lean" and "lean construction". It usually refers to the methods and principles for the design management process. Jørgensen and Emmitt (2009) proposed that lean design is as vague as lean and lean construction in terms of their definitions. In the next section, it is tried to have a deep view to the history of lean and lean construction in order to have a view of their histories and development patterns. The author of this thesis is not believed that there is a need for have a fixed definition for "lean" however it is believed that by having short summary in the next sections, *lean* would be more clear.

2.2 Lean production

The lean philosophy is developed by Toyota Company under supervision of Engineer Ohno. Before Toyota Lean Production philosophy, the car manufacturing business was dominated by American car manufacturing companies, mostly Ford and General Motors. At that time, American companies were following the Henry Ford mass production by focusing on craft production. Ohno and other Japanese engineers had a site visit of Ford Company and were familiar with the idea behind their systems. While visiting Ford, Ohno understood that American engineers care only about efficiency whereas Ohno looked at the waste in every part of American companies (Baines et al., 2006).

Ohno noticed in this production way, that imperfections often occurred because of unusual pressure to the production lines to keep producing. Ohno concluded that this puts pressure on every single unit of production and results in over production – he

pointed this as *"the waste of over production"*. He also believed that in order to increase productivity and have a more efficient company the attention should be moved to the whole production line instead of focusing on single production units and trying to increase their efficiency (Baines et al., 2006).

When the group of Japanese engineers returned to Japan from their Ford visit, they decided to implement the lessons learned by observing Ford's production way. They decided to focus on worker productivity in Toyota. The biggest changes that happened in this shifts of views was the shift in considering the waste. While both Ford and Toyota were trying to reach zero waste; American tried to keep pressure to maximize line production though Toyota saw this view as a manner that defects remain in the cars and will be delivered to the customers (Baines et al., 2006).

Moreover, he proposed that the circumstances of producing cars with nothing in inventory requires constricted coordination between different production lines and supply chains. In Ohno's opinion rework has no space to exist since it has affected production time and cause more workflow. Ohno even went beyond this point and asked workers to shut down the production line in a case of receiving a defective part from upstream flow. The changes in the production, which Ohno implemented in the Toyota factory, brought some other advantages to the company. For instance the notion that any worker can stop the production line results in decentralized decision making in the company. Transparency and decentralized decision making are two notions that usually complement each other. In the Toyota case, it was also recognized that transparency has been brought to the company along the decentralized decision-making. This transparency allows employees to see the production objectives easier therefore make wise decisions to support the production (Baines et al., 2006).

Step-by-step, Toyota understood the benefits resulted from focusing on minimizing the waste in their production lines. They looked back to the design phase to get more benefit of having this focus on the design phase as well. Looking into the design phase had some important benefits for Toyota. Firstly, by speeding up the design process time, which is an important element for companies in hectic world of business, time allocated to design decrease so company can stay up to date. Moreover, connecting design and production made design team aware of the reality in the production line so design teams were aware of the production processes (Baines et al., 2006).

Although the Lean production keeps changing under some special circumstances, the basic principles stayed clear and fixed as follow (Baines et al., 2006):

- Focusing only on the products/items which add value to the customer and ignore anything which does not have any value for customer
- Consider production as a continues flow and not as an isolated phase
- Make product as good as possible, reliable flow in the production line, decentralized decision making and distributed information
- Deliver a product with specific customer specification with nothing in inventory

All in all, lean production is a new approach to the design and production, which is completely different from mass production. It uses different techniques in the production level, design level and supply chain (Baines et al., 2006).

2.3 Lean Construction

Applying the lean philosophy to construction seems impossible at first since there is a trend in construction, which emphasizes, *"Construction is different"*. The author of this paper sees this as a syndrome in construction. In the past two decades most of the innovations in other industries were neglected by construction due to the idea indicating that construction is completely different from other industries (Dubois and Gadde, 2002).

Lean construction was one of these new methods first applied in manufacturing. After a while, a few construction scholars proposed that it is possible to use lean principles in construction while others believed that lean is one of other fads that will disappear after a while. Considering both views, lean principles and lean construction are considering as two ways of work right now.

Views to lean are divided between two different fields. Some argue that applying lean in construction is possible if only the principles, which used first in *Toyota* are applied in construction. This group focuses on eliminating waste, improving productivity and performance measurement. They look at lean more as a new mindset for different project participants. While others believe that managing construction according to lean is different from what is happening in manufacturing. The second group argues that other industries have clear delivery objectives, clear plan to maximize performance according to the customer requirements at the project level, production control is a continuous flow during the life of the project and product and processes design simultaneously, though construction does not have these characteristics. Therefore, it is necessary for construction to look at the bases of lean and transform it to its own version. That was how Lean Construction (LC) developed.

By conducting a literature review the author of this thesis believes that term lean design and lean production have been applied to a variety of different ways, methods and principles in both design and production phases. All in all, the author decided to use the term lean design as an approach in which project teams/organizations – and to some extent many stakeholders – work integrally together in order to deliver a project by a lean approach (Jørgensen and Emmitt, 2009).

It is worth noting that Jørgensen and Emmitt (2009) believed that there are four ways of integrating lean to construction:

- Integration in construction supply chain management either horizontally nor vertically and in between construction delivery and management of real estates (Bröchner 1990, 2003)

- Information systems integrations for processes and product (Anumba et al. 2004)

- Integration working practices and collaborative processes (Austin et al., 2001, 2002; Baiden et al., 2006)
- Aspects related to constructability and methods and ways to improve it

Integration working practices and collaborative processes proposed by Austin et al., 2001, 2002; Baiden et al., 2006 is an aspect of integrating lean into the construction which is highlighted in this thesis.

3 BIM

The construction industry has long sought to overcome the mentioned challenges and increase construction productivity. It is argued that BIM (Building Information Modelling) is a solution to achieve these long standing objectives (Azhar et al., 2008). There are many different benefits and advabntages mentioned for BIM by many scholars. For instance, CIFE (Stanford University Center for Integrated Facilities Engineering) in one of its report (CIFE, 2007) reported the following benefits for BIM according to 32 major projects using BIM:

- Up to 7% project time reduction
- Up to 10% saving of contract value by clash detections
- Increasing cost estimates accuracy to 3%
- Up to 80% reduction in time used for preparing cost estimates
- Up to 40% dismissal of unbudgeted change

But what could be a good definition for BIM. A quick look at academic literature shows that there are different definitions for BIM and this section lifts up some of the different perspectives on BIM.

There are several inconsistencies and different perspectives towards BIM definitions (Jernigan, 2008). The definitions could vary depending on the user's point of view, type of organization and their particular work emphasis.

- From a design perspective, BIM is defined as the digital representation of the physical and functional characteristics of a project (AIA, 2002), which refer to the process and technologies used to create a BIM model.
- From the construction point of view, BIM is considered as the development and use of a computer software model to simulate the construction and operation of a faculty (AGC, 2006).
- For facility managers, BIM may be a powerful new tool to enhance a building's performance and manage operations more efficiently throughout a building's life. It is worth noting that the latest use of BIM in facility management is a new approach in using BIM which calls for further researches.

Different organizations, research and institutes define BIM in various ways. For instance, the National Institute of Building Sciences (NIBS) defines BIM as the following (NIBS, 2007):

"Building Information Model or BIM utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/life-cycle information, and it is

intended to be a repository of information for the facility owner/operator to use and maintain throughout the life-cycle of a facility."

Another definition of BIM is proposed by Van Nederveen et al. (2009) as:

"A model of information about a building that comprises complete and sufficient information to support all lifecycle processes and which can be interpreted directly by computer applications. It comprises information about the building itself as well as its components, and comprises information about properties such as function, shape, material and processes for the building life cycle".

With these features most BIM users aim at achieving cost savings and try to ultimately include integrated cost modelling, construction sequencing and facilities management (FM) capabilities. However, there are many likely possibilities for different interpretations of BIM as the result of various distinct definitions of BIM. For example, some may argue that BIM should be regarded as the entire process exchanging, reusing and controlling project information being generated during the lifecycle of buildings while others consider it as just a simple information modeling. Some can just describe it as a 3D digital representation of the physical building while another group may discuss the idea of creating a single repository of information about the building which can be of use throughout its lifecycle, while others focus on the collaborative aspects of BIM. Moreover, some users consider BIM as an advanced Computer Aided Design (CAD), while others take it into account as a series of models for distinct elements of a project. The most obvious difference of BIM in comparison with CAD is that CAD depicts construction elements with lines that define a structure's geometry; however, BIM creates each element of the structure as an "intelligent" object containing a broad array of information in addition to its physical dimensions. Each element in the BIM model relates well to other objects and to the design in general (Jongeling, 2008).

The definition that is used in this thesis to describe BIM is based on the definition of Azhar et al. (2008). They define BIM as follows:

"Building Information Modeling (BIM) represents the process of development and use of a computer generated model to simulate the planning, design, construction and operation of a facility."

A BIM model carries project functional and physical characteristics along with the project life cycle information as smart objects. Also, a BIM model can carry geometry geographic, quantities and cost of elements. The knowledge that is included in BIM results in many benefits. For instance, by using BIM, quantities of materials can be calculated easily, identification of the scope of work for each party – either contractor or consultant – is smooth, sequence and assemblies of work is easily recognizable and the construction drawings, specifications and procurement details can be interrelated easily (Khemlani et al., 2006; Azhar et al., 2008).

There are some general benefits mentioned for BIM (Azhar, 2011):

- Visualization
- Fabrication drawings:

- Accurate Cost Estimate
- Easy Code reviews
- Understanble construction sequencing
- Collision, conflict detection
- Facility management

There are some benefits that Azhar et al. (2008) and CRC (Construction Innovation, 2007) mentioned for BIM as follow:

- The accurate representation of the building objects
- Effective processes: since information is easily shared and reused
- Efficient design: BIM gives the chance to architects and managers to analyze the design proposals and choose the best design in terms of cost , budget and scope
- Better control on whole life data of buildings: it ease the performance benchmarks, better understand of life cycle costs, better access to the details designed objectives and more predictable environmental performance
- Increase quality in production: Flexibility in documentation output and increase use of automation in construction
- Automated assembly: it helps standardization of construction objects so increase manufacturing of structural systems
- Better customer service: visualization that BIM brings to construction help customers to better understand different proposals in the design phase
- Better Facility management: life cycle data of buildings that are stored in BIM models, such as requirements and design, construction information, helps facility managers to reuse them easily so there is no need to recapture that information again.

According to Eastman et al. (2008) effective use of BIM may bring several remarkable impacts on a project outcome through improved design, improved constructability, and quicker project completion, saving time and money both for the owner and for the project team. BIM is also emerging as the solution to reduce waste and inefficiency in building design and construction.

BIM is being used in a number of different levels of maturity. As the first level, it is used as unmanaged CAD, in 2D, with paper or electronic paper data exchange. In the next level it may be utilized as managed CAD in 2D or 3D format with a collaborative tool providing a common data environment with a standardised approach to data

structure and format. In this case, commercial data will be managed by standalone finance and cost management packages with no integration. In the next stage BIM is used as a managed 3D environment held in separate discipline "BIM" tools with data attached. Commercial data will be managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilise 4D construction sequencing and/or 5D cost information. And at the highest level of BIM it is considered as fully integrated and collaborative processes enabled by "web services" and compliant with emerging Industry Foundation Class (IFC) standards. This level of BIM will utilize 4D construction sequencing, 5D cost information and 6D project lifecycle management information.

3.1 Current state of using BIM

It has been recently observed that many changes in the context of architectural design are affected by information technology (Penttilä, 2007). For instance, in a survey by a Nordic IT-barometer scanning firm it has been found that around 70%-80% of project drawings are produced digitally these days (Penttilä, 2007).

Kunz and Giligan (2007) conducted a survey in order to determine the current value of BIM and factors lead to a more successful use of BIM in the US construction industry. They concluded that the major use of BIM is in construction document development, pre-project planning and conceptual design. Their study further proves that the use of BIM results in increasing construction productivity, more employee participation in the project and reduce in the number of contingencies (Azhar et al., 2008). There was another survey by Khemlani (2007) which aims to find out the goals BIM professional asks BIM to satisfy. Her survey indicates that the users ask BIM not only to increase the visualization capabilities of pre CAD software but also they ask for software supporting design and management aspects (Azhar et al., 2008).

According to Haymaker et al., (2000) collaboration is essential for architectural design in civil, construction and mechanical engineering. Managing requirements of design recently became as one of the important project information processes. Despite the fact that having design requirements early in projects help designers a better design; another important issue in the early design phase when client wants to approve a design proposals is the ability of the architects or designer to present designed proposals to the client clearly (Penttilä, 2007). As Azhar et al. (2008) also noted, the author of this paper believes that BIM helps the construction industry to accelerate coordination and collaboration in project teams which lead to better time management, cost reduction, increase profitability and better relationships between different project stakeholders.

BIM brings a unique advantage to the construction industry in terms of participation of all stakeholders in projects – especially early participation of many stakeholders – that results in twofold; firstly greater efficiency of stakeholder participation; secondly the harmony that is an outcome of this participation. There is a treat to this advantage which is the elimination of significant check and balance mechanisms in the traditional way of work. In other words since all players participate in most phases they may be lazy to find mistakes in other members' work since they may think this model is a final proved model for work (Azhar et al., 2008).

4 Integrating BIM & Lean

It is believed that BIM can facilitate implementing lean. There are numerous advantages are mentioned as interaction between BIM and lean. For instance, it is proved that BIM can help lean visualizing and focusing more on the work flow (Sacks et al., 2010).

However, there are a few papers that describe how BIM and lean can complement each other in the AEC industry. Many different interactions of BIM and lean were noticed. Some author like Sacks et al. (2010) developed a matrix for the possible interaction of lean and BIM by conducting an extensive literature review. The Sacks et al. (2010) matrix has 56 elements, as possible interactions of BIM and Lean, though finally they could find only 4 out of those 56 elements are proved to be synergetic interactions of BIM and lean. Sacks et al. (2010) look at the interactions of BIM and Lean in a matrix format though many other scholars have different views. They also emphasize the important role of this interaction in the design phase, which can be beneficial for the projects in the later production phase.

4.1 Collocation and collaboration

Tjell (2010) discussed that *lean design* can be generally regarded in the broader concept of Target Value Design (TVD). TVD itself can be considered as a widened concept of Target Costing (Ballard, 2000; 2006).

TVD is divided to five sub-categories as follow:

1. Production System Design (PSD)
2. Collocation
3. Collaboration
4. Set-based design
5. Target costing

This thesis focuses primarily on the use of a single location in which design meetings take place, i.e., a big room or iRoom. The iRoom or Big Room is discussed in more detail in section 4.3. The iRoom is mainly a name of a space – usually one big room in which design team members can collaborate and work on the design - equipped with different useful electronic devices to enhance sharing information and have better collaboration among the people who gather in the room. Therefore, the aspects of collocation and collaboration have the highest importance in the scope. Since the focus of this thesis is on investigating iRoom meetings so only two aspects of TVD – collocation and collaboration – are discussed in more detail.

4.1.1 Collocation:

Collocation refers to forming a design team consisting of different organizations participating in the project that are working together in one definite place/office.

Design teams usually consist of contractors - general contractor and some sub-contractors - engineers and designers representing different organizations and architects. However, the roles and disciplines represented in the design teams vary a lot depending on the type of projects and many other factors.

Regardless of project participants, the term "collocation" in the design phase is applied when a design team uses a particular room, which is usually occupied with different electronic equipment, to share information between participants. This place is called the Big Room or the iRoom (Tjell, 2010).

The Big Room concept, which focused on having design teams consist of different project participants can be either discussed in the context of concurrent engineering, Integrated Project Delivery (IMP), Lean and/or BIM (Tjell, 2010).

Many advantages of working with iRoom were reported by organizations that focus on BIM and lean, e.g., the Lean Construction Institute (LCI) as well as the American Institute of Architects (AIA). These organizations noted the advantages for forming a design team consisted of different organizations. AIA argues that it is regarded as the best way to form a design team to use all the competencies of BIM (Tjell, 2010).

4.1.2 Collaboration:

Setting up the collaboration channels is crucial in forming design teams. The defined ways of communication and sharing information between different stakeholders/organizations participating in the project helps all stakeholders to have access to the needed information in a timely manner. Also, it ignores future conflicts between actors, which can occur in the later phases. The incontrovertible importance of collaboration in the integrated design teams, which consists of different stakeholders, should be taken into account not only because of more number of participants from different organizations but also in order to ease sharing information which is hidden in each single actor database.

However, the importance of collaboration in integrated design teams is visible; it may not be that obvious from a lean perspective. In the next paragraphs, the importance of collaboration is explained from the perspective of the lean philosophy.

Liker (2004) mentioned the importance of collaboration; according to the lean philosophy all actors should understand the whole work process in order to be able to see the waste, eliminate it and focus only on value adding activities. Therefore, a creative atmosphere should exist for the design teams so all members understand the adding value activities and non-adding values.

The idea of having a particular room designed to support multi-disciplinary collaboration and collocation - "Big Room" or "iRoom" – is deeply rooted in the lean philosophy. The big room can create an atmosphere in which sharing knowledge and information between different actors supports collaboration so all design team participants can see the flow stream; therefore, be able to focus on the value instead of waste. Thus, the ideas behind lean are enforced.

In order to have such an environment there are some issues need to be addressed. The idea of a Big Room calls for having a room where different drawings or design

alternatives have the opportunity to be presented and judged so the best design can be picked. Moreover, this room should be equipped with facilities that support collaboration and visualization since visualization is the most effective way to present ideas. Having a data storage system also seems crucial since it helps all actors to access information easily and also increases transparency. The mentioned requirements for this room can be fulfilled by using BIM. BIM enables visualization for presenting ideas of different actors while is a reliable data storage system.

Collaboration and collocation are two concepts that are centered to the lean design. However, it is not only the physical room and ICT – mainly BIM - that supports collaboration. Also the availability of working principles, techniques, and methods to collaborate are important to consider.

Apart from notions of collocation and collaboration in TVD, some other connections between lean and BIM were noticed during the literature review. For instance, lean philosophy encourages the idea of integrating design and production. In other words, it proposed that the construction production should be started form the design phase (Koskela, 2000; Ballard and Zabelle, 2000; Ballard, 2002).

4.2 Relationship between Lean Project Delivery (LPD) and Virtual design and construction (VDC)

4.2.1 Virtual design and construction (VDC)

The iRoom has been studied in relation to the "Virtual Design and Construction" principle developed by the Center for Integrated Facility Engineering (CIFE), Stanford University, USA.

They are one of the centers which focus on Virtual Design and Construction (VDC) as a contemporary view to design building – facilities – using virtual reality, though there are other scholars that discuss BIM and VDC from different views. In this chapter it is tried to discuss VDC from different perspectives.

One definition for Virtual Design and Construction which is proposed by CIFE is:

"Virtual Design and Construction (VDC) is the use of multi-disciplinary performance models of design-construction projects, including the Product (i.e., facilities), Work Processes and Organization of the design - construction - operation team in order to support business objectives."

The VDC consists of many different techniques, views and methods, which are mostly proposed or studied by CIFE in order to bring virtual reality into the construction. One of these ideas is the "iRoom" – a project studio for design processes. This idea is discussed in the later chapters (4.3).

One of the CIFE reports which is titled *"A Guide to Applying the Principles of Virtual Design & Construction (VDC) to the Lean Project Delivery Process"* is focused on explaining VDC concepts and principles and describing how these concepts can be applied to the Lean Project Delivery System (LPDS).

The LPDS concept is developed by LCI describing how lean principles can be applied into the construction projects. This report is one of the best report has ever written in the AEC industry trying to explaining the relationships between VDC and lean.

4.2.2 Lean construction and Lean Project Delivery System (LPDS):

As it mentioned before, Lean Construction Institute (LCI) was an institute, which tried to popularize lean concept among construction managers, organizations and engineers. They tried to apply Toyota Production System (TPS) into the project delivery process of construction industry.

The aim of implementing Lean in construction and name it Lean Construction and the idea behind the Lean Construction are noted as follow:

"The ultimate goal of lean construction is to eliminate waste from construction and deliver a product that a customer wants, instantly."(Khanzode et al., 2006)

And

"The basic idea behind the lean construction is to manage the construction project delivery as a lean construction system" (Khanzode et al., 2006).

Therefore, the aim is to eliminate waste from construction, which is a phenomenon in construction; however, the idea behind it is to implement a new principle of work. By implementing lean construction, lean construction pioneers, aimed at changing the existent unproductive project delivery way.

By implanting lean principles in construction, LCI suggests a new way of project delivery for construction based on the lean principles. They named it as Lean Project Delivery System (LPDS). The aim of LPDS is:

"LPDS is envisioned as a project delivery method that conceptualizes design and construction projects as lean production systems" (Khanzode et al., 2006)

Some of LPDS elements take the importance of downstream process and players into account. Also, value has been given to the planning processes, conceptualizing the project delivery and making a dependable workflow in connection with project participants.

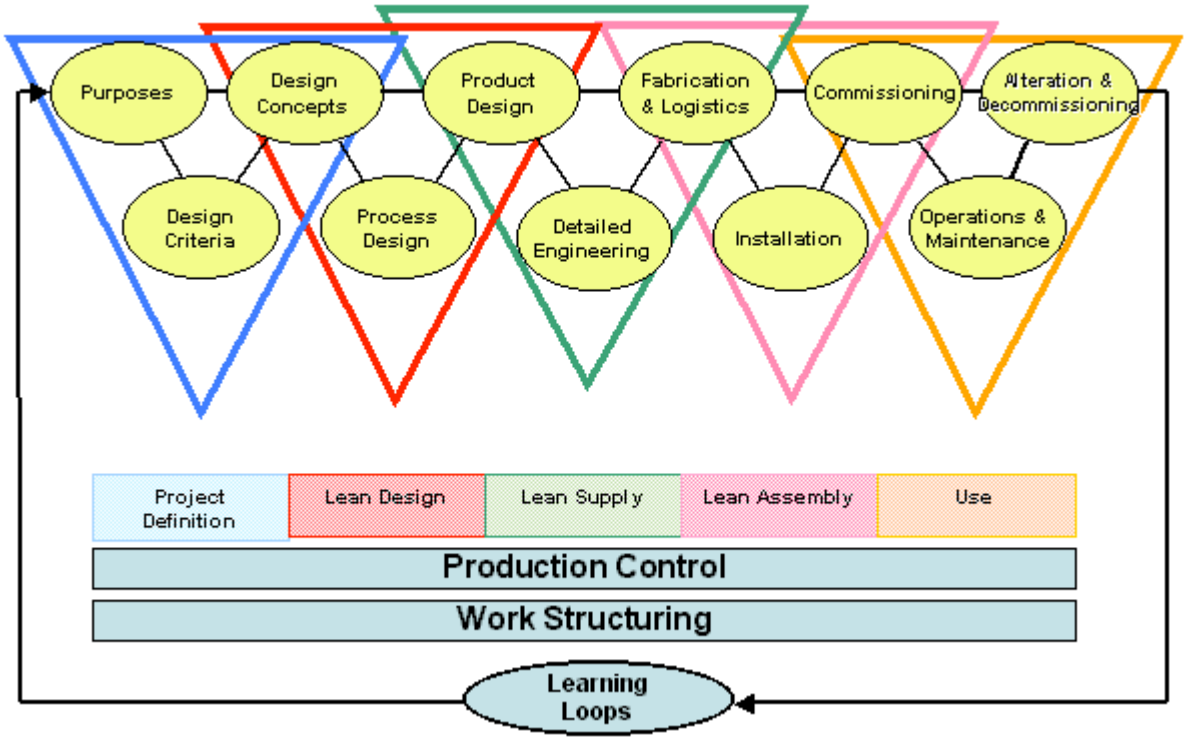


Figure 1. Lean Project Delivery System (source: Ballard, 2000)

Ballard (2000) argues that the LPDS consisted of 5 interconnected phases as:

- Project definition
- Lean design
- Lean supply
- Lean assembly
- Use

Khanzode et al., (2005; 2006) discussed the possibility of implementing many different VDC tools and techniques during different stages of the LPDS. They found that it is not only possible to use many of the techniques and tools of VDC in different stages of LPDS but also there are synergies between some of them.

"LPDS emphasized the need to incorporate construction knowledge in the design process." (Khanzode et al., 2005; 2006)

By investigating different construction projects as examples, Khanzode et al. (2006) showed that specific VDC techniques and tools can be used in different stages of work described by LPDS. Although, unsurprisingly, the relationship between VDC and LPDS in a narrow perspective, or better mention as BIM and lean in a broader perspective, was shown by other scholars earlier; Khanzode et al., (2005; 2006) tries to highlight these relationships by giving specific examples. They argued that:

"LPDS provides a framework for structuring the project delivery process but does not provide specific tools or methods to accomplish the objectives of a lean production system. The tools, technologies and methods of the VDC framework provide the best toolset we know to accomplish the ideals of the LPDS. The objectives of both approaches are the same: to help improve the construction delivery process." (Khanzode et al., 2005; 2006)

Khanzode et al. (2005; 2006) concluded that VDC is an enabler of the LPDS principles. Although it is believed that LPDS is more a process based view, the Khanzode et al. (2005; 2006) report has a more practical approach which is based on the application of different technologies and techniques to visualize the construction.

4.3 iRoom

"Decision making in project meetings requires the application of the interdisciplinary knowledge of a multi-disciplinary project team." (Schreyer et al., 2005)

An important issue that should not be underestimated in a design meeting is the importance of collecting information/knowledge that requires collaboration among various organizations participating in the project especially when all of these participants have different backgrounds. Having different backgrounds makes it hard to gather the required knowledge since the language, terms and content knowledge that different disciplines rely on, varies a lot. In design meetings which different organizations with different backgrounds participate, making decisions seems problematic due to the nature of meetings. To obtain a solution to deal with the mentioned problems, firstly, the current way of collaboration in design meetings should be investigated; secondly, a proposed solution may be examined (Schreyer et al., 2005).

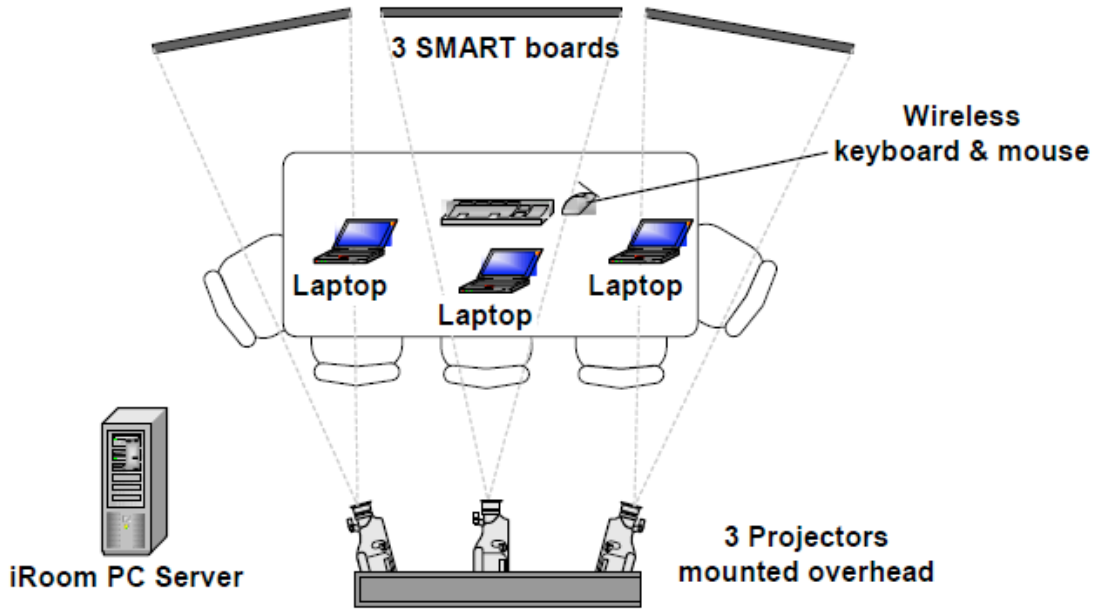
Traditionally different disciplines present their drawings/plans in paper format in design meetings since there was no such a definite electronic format for drawings and/or lack of necessary equipment such as projectors. As Liston et al. (2001) emphasized presenting information in paper format bordered the project team's abilities to collaborate softly and effectively, making decisions and solve project problems because:

- Static nature of paper-based information makes it impossible to apply necessary changes immediately. Therefore, decisions are postponed to a next meeting which paper-based information are presented correctly (Liston et al., 2001).
- Complexity adhered to discipline-specific modeling makes it hard for other disciplines to understand and analyze other disciplines' models (Liston et al., 2001).
- Views are not prepared to use by all project meetings' participants since they are presented in different levels of details (Liston et al., 2001).
- Participants in project meetings have different views towards cost, scope and other project specifications, which are not communicated in drawings (Liston et al., 2001).

CIFE developed and marketing a multi-disciplinary and multi-actor hardware and software environment as "Construction Interactive Workspace" or "iRoom" that eases the collaboration in meetings in different construction phases. In other words, it helps the meeting participants to have an atmosphere in which all participants are able to present their knowledge/information in a way that this knowledge/information is easy to understand for other participants (Fox et al. 2000; Schreyer et al., 2005).

4.3.1 The iRoom Environment

There are numbers of different ways of how an iRoom can be designed; some scholars like Hartmann (2003) and Johanson et al. (2001) discussed the ways iRoom should be formed. They argue that software like AutoCad, Autodesk's Architectural Desktop, MS Project and Excel and Common point's 4D CAD Modeler should be used in order to show the needed data to other meetings participants. CIFE also mentioned the iRoom layout too. Three smart boards with projectors and a touch screen, wireless keyboards and mouse and a server to keep the shared data are also mentioned as a layout for Stanford CIFE iRoom (Schreyer et al., 2005). It is worth noting that although CIFE proposed a model for iRoom, this cannot be considered as a definite way for forming iRoom. The important point here is to focus on the collaboration; so the room which is used for holding design meetings should be equipped with sufficient facilities that facilitate collaboration, communication and exchanging data and information during design meetings.



Picture 1. One of the proposed layouts for iRoom (Source: Schreyer et al., 2005)

4.3.2 iRoom meetings

By having the idea of an interactive workspace, it would be interesting to have a closer look at what is exactly happening in the design meetings.

It is believed that the most important advantage of iRoom is the diverse project views by different project organizations (Schreyer et al., 2002; 2005). While architectural firms present their visual views in AutoCad format, project managers present advanced opinions – usually regarding time plans - in MS Excel, MS Project and PrimaVera; the client may be more interested in the data connected to the cost and schedule of the project (4D and 5D BIM). These different ways of presenting information is made easier in the iRoom since the different organizations try to use a common language so other organizations understand it. Moreover, the notion of sharing information in one shared database makes project details transparent. There are some other advantages of working in an iRoom as the importance of visualization in iRoom, which enables participants to understand information partially related to their fields of experience in a better way (Schreyer et al., 2002; 2005).

Although, many researchers have stated that holding design meetings using iRoom are advantageous, (Schreyer et al., 2002; 2005) there are some concerns related to having design meetings in iRoom. For instance, having different views to making project schedules and budget estimation and having different file formats make it problematic to use the iRoom idea in the beginning; however it is believed that literally these issues have been solved and holding design meetings with the iRoom idea is becoming more and more common in the AEC industry.

5 Method

There are many different ways mentioned for conducting research. In order to do a thesis many different ways can be chosen, examined and used. The main steps in the thesis research are the pre-study, the literature review, the data collection with help of a case study and interviews, then data analysis and finally summing up the results.

5.1 Pre-Study

The pre-study is one step that its importance is not mentioned explicitly by traditional methodology sources though, in my opinion, it was very helpful indeed.

The aim of the pre-study was:

- To examine the possibility of writing a thesis in the field that I am interested.
- To have a very brief list of useful research papers and thesis in the field of study.

5.2 Literature review

The literature review is the second step that helps the writers to go deeply through many research papers, reports and thesis; choose the most useful ones and start using the empirical ideas which has been reported and/or suggested by other authors (Bryman, 2008). Bryman (2008) argued that performing a literature review is a step in conducting research that helps the writers avoid doing unnecessary works. In other words, by having other authors/scholars ideas the writer of a research paper can stop doing rework in his/her research.

5.3 Qualitative vs. quantitative

There are two main methods/categories in doing researches: qualitative and quantitative.

Quantitative research is a method that is used mostly in circumstances when there is already a hypothesis that needs to be tested. In other words, quantitative research tries to establish a framework for examining a hypothesis by doing needed tests and gathering and examining the data (Holme and Solvang, 1997).

But the qualitative research is a method in which there is no need for raw data of examinations or hypothesis. In qualitative research, a researcher tries to investigate an idea/theory and/or a case in different ways; for instance, investigating a case study, conducting interviewees, using questionnaire etc. (Holme and Solvang, 1997).

Due to the unique nature of the iRoom design meetings, there are few research papers available that have done real case studies in the field. Therefore, it was interesting to see how iRoom works in the industry. Consequently, I have chosen case study method for doing my thesis.

Moreover, I have chosen to have interviews as the main way of gathering data from my case studies and observe how iRoom design meetings works and how it is integration between BIM and lean.

5.3.1 Case Study

The chosen method for doing this thesis is the qualitative. After doing pre-study, it has been concluded that it would be useful to have a real case/project. The Case study is a method in which a researcher can make a connection between the theory and real case/s (Yin, 2009).

So it enables the researchers to compare the findings from the literature review with the case study data that can be found in a real case. However, there are some limitations for having only a single case study because it can border the findings to only one single company that may suffer from different external and/or internal elements. Thus, the importance of all elements in the case study should be taken into account. In addition, it would be impossible, irrational and amateur way to generalize findings from only one case study to the industry. It has been tried to consider the importance of these issues in my case study.

The case study chosen for this study is a contractor company that has started to implement the idea of iRoom. The company is located throughout Sweden. As it mentioned, in this thesis, it has been decided to choose a case study for evaluating the iRoom atmosphere according the BIM and lean aspects. There were a few points that persuaded the author of this thesis to use case study method:

- Availability of a big firm that implemented using the idea of iRoom recently in many of its branches in Sweden

- The possibility of compare the practical work to the iRoom theories.

5.3.2 Interviews

There are a number of different ways in order to collect data from a case study, i.e., using interviews, surveys and observations can be used. It is more dependent on the researcher to choose between these methods and decide which one suits its case (Yin, 2009). For this particular study it was chosen to perform interviews within the case study by Skype. This was primarily because the interviewees were spread throughout Sweden.

However, there are limitations to interviews as well. A very first downside of having the interviews is finding the right people to be interviewed. In my case, it was definitely one of the hardest parts. Moreover, it is sometimes hard to communicate with your interviews, due to many different social reasons. Having a few interviews, considering the scope of your research, may harden using the interviews' outcome as a reliable source.

In order to collect the data for answering the research question, the researcher has selected interviewees who either are responsible for BIM, the iRoom idea, Lean, or who work with these concepts.

Six interviews have been conducted from mid March to the beginning of May. All interviewees have had the roles of architects/BIM managers/project studio managers. The interviews had durations between 35 to 50 minutes. All of them were written down afterwards and analyzed immediately.

The interview questions were developed with help of the literature review and my supervisor. The interview questions concern BIM, lean and the connections between them, a selection of the interview questions is mentioned below:

1. What could be the next step in developing BIM as a design tool?
2. What are the advantages/disadvantages of sitting in one room and listening and sharing your thoughts?
3. How does BIM influence you in your daily work?
4. Could you define that what are the current ways of using BIM in design phase? How do you hold your work meetings?
5. Are the current ways of holding work meetings in the design phase suitable for a beneficial use of BIM?

5.4 Data analysis

In order to analyze the interviews, firstly, I asked the permission, from all of my interviewees, to record the interviews so I was able to listen them again and again. Secondly, all the interviews were written down. Then it was tried to find the main theme in each interviews related to BIM, lean and/or both. It was also noticed that although I have interviewed the managers of one company, mostly in its different branches across Sweden, there are some contradictions as well as similarity in their answers. Therefore, as an interesting issue, it has been tried to analyze the interviews regarding on them and highlight the contradictions and similarities in the interviews' answers.

6 Interview findings

6.1 Introduction

In the interviews it was asked which organizations and persons were involved during these design meetings. Most interviewees listed the same disciplines present during these meetings. In these meetings the following disciplines or roles were present: one architect and one engineer form each discipline, a project manager, and one person representing the production – usually site manager or its representative. It was noted by all interviewees that the client is usually invited though they participate rarely in design meetings, however, their presence in design meetings is only considered as an observer who cannot decide on the technical issues discussing in these meetings.

6.2 iRoom design meetings

In my research, I focus on one company as my main case. This company implemented using iRoom as main place for having design meetings. The idea of this room is based on iRoom and/or Big Room. It is important to look at different projects directed by different branches of this company and investigate how they use the iRoom idea. My findings can be categorized as following:

1. Sharing of Information
2. Visualization
3. Coordination
4. Collocation
5. Communication
6. Lean

In this section, the findings from the interviews are discussed.

6.2.1 Adding and sharing Information

Different aspects of sharing information were described by the interviewees. In this part, it has been tried to investigate findings from the interviews that highlight the notion of sharing information.

One of the interviewees described working in iRoom as a place where all consultancies gather once a week and the model is available. The people work together in order to produce the best possible model. Based on her words, this model is helpful since:

"The shared model helps everybody has the same picture of what the discussion is based on"

She also highlighted sharing information as one of the main uses of BIM in the iRoom design meetings. Moreover, she believed *"the project studio is one of the best ways of putting information to the project"* though it is still not the common way of having design meetings in the whole company. She also believes that there is a future for it since it is advantageous.

Another interviewee believed that sharing information results in having a shared model, which can be viewed from different perspectives by different disciplines in one meeting. Moreover, she believed that it helps design team to choose the best possible model. So company can get benefit of these iRoom design meetings and save money and time because the best model will be designed. Despite the advantages she mentioned for the 3D models resulted from iRoom design meetings, she indicated that they use 2D drawings as the basis for making decision. However, she believed that if it is possible to add more information from the beginning of the project to the 3D model, 3D models can replace 2D drawings during the whole process of design and production.

Another interviewee claimed that sharing information results in reducing the answer time to the questions is one of the general advantages of having iRoom design meetings, though she mentioned difficulty in having access to the personal database in meetings harden sharing information in design meetings and sometimes it is needed to update the model after the meetings which is not easy and comfortable.

In another interview, the interviewee believes that this way of holding design meetings is the best way for collecting information since it helps the construction companies having more accurate estimation from the final models that are produced by the iRoom design teams.

Also, having different file formats considered as a big obstacle for sharing information in the meetings by an interviewee which shows the lack of a common server and maybe lack of making early decision on working with specific software.

Sharing information is not only interesting to investigate from different perspectives that people mentioned in their interviews but also it would be advantages that almost all interviewees consider information as the main base of BIM. Comparing definitions that they mentioned for BIM proves this statement.

One of the interviewee had a comprehensive definition form BIM as *"Building Information Modelling"*. She highlighted the importance of information – which can be directed to different directions - in BIM in order to make a virtual model of a building. She considered BIM as a 3D model which is possible to be used as a 4D and 5D model as well by inserting more information.

Also, another interviewee defined BIM as:

"3D model contains all information, as a database; used for takeoff, planning, coordination, collations."

"BIM is when you add information to an object in a virtual environment …and then you can present this information in many different ways so it is a collection of information."

"Using different set of tools to be able to predict and be sure of what you are going to build … people understand of what they are going to build. It is very much about information and understanding information and information handling."

"BIM is building information models with information accessible and usable overtime."

All interviewees mentioned the notion of adding, keeping and sharing information as a base for defining BIM. It shows the importance of adding and sharing information for the people works in the design phase. In addition, it can prove how design teams consider information as one of the most important aspects in their daily work while they all believe that it is dedicated to BIM.

6.2.2 Visualization

Visualization and its use in design meetings is an issue that is continuously repeated by the interviewees.

All interviewees believed that visualization brought many advantages to the construction sectors. One of the interviewees claimed that by having visualized models nowadays, calculation and drawing out the proportions and clash detection became much easier. She did not consider either BIM or lean as the bases of visualization.

However, two other interviewees emphasized the important and useful uses of BIM in the iRoom design meetings for clash detection and quantity take offs which results in saving time and solving projects' problems easier and cheaper. She considers visualization as an advantage, which is brought to the construction by using BIM; though another interviewee believed that visualization is both a BIM and lean approach to the design. She argues that the use of BIM in iRoom design meetings results in the use of visualization and consequently better quantity take offs. However, she highlighted that the iRoom is based on the lean principles, collocation and visual planning. Therefore, she considered visualization as a lean tool, which is brought to the iRoom design meetings by using BIM and not as a lean tool that are supported by BIM.

Accurate estimation of quantities is not the only result of visualization mentioned by interviewees, one of the interviewees mentioned that they started to add budget and time step by step in their visualized models. It shows that they started using 4D and 5D BIM in their work though the interviewee was not sure to call it as 4D and 5D BIM. She mentioned it as follow:

"I am not sure to call it 4D or 5D but we start adding budget to our model"

Visualization is not only a method that is used inside the iRoom design meetings and in the design phase but also, as it noted by an interviewee, it can be used in the production phase to assist contractors. For instance, an interviewee mentions that

"I take pictures from different parts of the project 3D model, which needed careful considerations by other stakeholders, then show the pictures to the other stakeholders – contractors and sub-contractors usually – and highlight the importance of those parts for them."

6.2.3 Coordination and collaboration

Coordination is another use of iRoom design meetings, which was highlighted by all interviewees.

All interviewees mentioned coordination between different disciplines results in discussion a lot of issues in one meeting. This easy coordination between different stakeholders benefits the project because it helps project organization saving time and energy.

Also, it is noted that looking at one model from different perspectives by different disciplines in one meeting is one of the advantages of better coordination in iRoom design meetings. However, it is mentioned that lack of technology in iRooms can act as a barrier, which hinders the coordination issue.

Although interviewees counted many advantages for coordination, they mentioned that difficulty in having the right people in the meetings may hinder the meeting process and coordination between different disciplines.

It is also worth noting that some interviewees considered better coordination as an advantage which is brought to iRoom design meetings because of BIM, though some other looked at it from a general advantage of iRoom design meetings. It is not the only insight to coordination in design meetings. It was also mentioned by one of the interviewees that the better coordination in these meetings occurred because of reducing the lead-time to answer questions by different disciplines.

The coordination is a part of the nature of iRoom design meetings. One of the definitions of these iRoom collocated design meetings by one of the interviewees defined these meetings as:

"It is like a coordination meeting with the decision need to be official and answer client needs".

He continues with emphasizing that the meetings have been planned before start. So it is decided what to be discussed in these meetings in advance. The importance of coordination in the eyes of design managers is too bold that they use it to define the iRoom meetings.

It should be noted that in all interviews, it is concluded that better coordination results in better collaboration between different stakeholders of the project organizations and add benefits to the project.

6.2.4 Collocation

The collocation is another aspect in iRoom design meetings, which was highlighted by interviewees. For instance, two interviewees described their design meetings as:

"... meetings in a big room that all consultancies gather once a week and the model is available… The people work together in order to produce the best possible model."

And

"... collocated meeting which is generally more efficient compare to the old way of holding design meetings."

Looking at different models from different perspectives by different meetings' participants is another advantage, which is considered as a notion which is brought to

iRoom design meetings since all stakeholders gather in collocated meetings. As it noted before, this results in saving time, energy and most importantly money for the company since the most suitable model will be chosen as the final model.

Also, it is highlighted that iRoom design meetings is beneficial due to free and quick accessibility to different engineers and architects from different disciplines in one room which is a result of having all discipline in one room.

Despite the fact that collocation brings many advantages for the construction; all interviewees mentioned some issues that can act as barriers to the collocation meetings. For instance, lack of a common server, different file formats and difficulties having the right people in the meetings are issues that decrease the advantages of collocated meetings and force meeting participants to add information to the model from their offices individually. One of the interviewees mentioned it as follows:

"It is sometimes hard to have right people in the meetings … this make meetings hard since these people need to check everything with other people and then come to the next meeting with their decision"

It obviously shows how some issues, like difficulty having right people in the meetings, can easily blacken the advantages of collocation and be an obstacle to the iRoom design meetings.

6.2.5 Communication

Another aspect that is highlighted by the interviewees is the easier communication resulted from the iRoom design meetings. I can highlight this advantage since all the interviewees mentioned it in the interviews.

It was observed that one of the interviewees considered easier communication in the iRoom design meetings has a connection to having shared information and model though noticed that lack of own privacy may cause problems for some of the meetings' participants. She argued that how lack of own privacy may hinder the communication with other meetings' participants since those who were disturbed by others' noise may not like communicate with others.

It is also noted that two interviewees considered better communication in iRoom design meetings as an advantage, which is connected to the use of BIM in meetings. For instance, one of the mentioned two interviewees highlighted the better communication as an advantage of BIM in design meetings as follow:

"I call it a walk on the designed site instead of having a walk through construction site"

However, other three interviewees counted this advantage as a general advantage of iRoom meetings.

It is worth noting that it is also mentioned that better communication save time by preventing employees to send extra emails and arrange extra meetings. One of the interviewees mentioned it as follows:

"They don't need to arrange another meeting and send strange emails …"

6.2.6 Lean

However all interviewees emphasized the important and useful uses of BIM in the project studio design meetings in many different aspects that result in saving time and solving projects' problems easier and cheaper, most of them were not able to describe lean aspects in their works in detail.

It was mentioned by one of the interviewees that the iRoom is based on the lean principles, collocation and visual planning. This shows that this interviewee was aware of the bases of lean and BIM.

It is worth noting that three of the interviewees were not able to discuss lean in detail and describing lean as a useful way of work which they know about it, though they were not able to describe lean in details. For instance, an interviewee had an outrageous quote about using lean as:

"I work with everything. I work with BIM and lean. I do the best I can and use those tools that I know about"

There was another interviewee who indicated that knows many things about lean. He further argued that he knows many things about lean, though he was not able to mention what they actually do with lean in their project. In other words, he was not able to explain lean and its uses in detail.

It is concluded that most of the interviewees were not aware of the lean uses and advantages in construction. However, they heard about lean in their companies; more specifically, they heard that lean is implemented in their process by their companies. But they were not able to discuss it in detail.

7 Discussion

In this section, it has been tried to discuss the interview findings in an academic context using some parts of the literature provided in the literature review parts. Numerous advantages mentioned by different interviewees will be discussed in this chapter. Nevertheless, it has been tried to consider and discuss the disadvantages as well.

7.1 Adding and sharing information

Adding and sharing information among meeting participants is an advantage, which was noted by all interviewees. The importance of this notion was highlighted by interviewees when they defined BIM. Information is also highlighted in BIM definitions which were proposed by NIBS (2007) and Van Nederveen et al. (2009). It shows that information is a very crucial aspect of BIM not only in academia but also in the business sector.

Having distributed information which helps having decentralized decision making and better processes is one of the main principles of lean (Baines et al., 2006). Moreover, collocation and collaboration that are mentioned as two bases of TVD have the aim to ease sharing of information among meeting/project participants (Ballard, 2006; Tjell, 2010). This issue covers my findings, which consider adding and sharing information as a vital core for the iRoom design meetings. Regardless of the interviewees' views that categorize it as lean or BIM advantage for iRooms; my findings show that the importance of it should be taken into account. It is proposed that the importance of obstacles that may hinder sharing and adding information should be taken into account by the project/design manager in the beginning of the iRoom design meetings in order to avoid later challenges.

A few issues noted as obstacles for the iRoom design meetings like having different file formats, using different software and lack of smart boards and professional computers, that are able to process 3D models, which are able to harden the information flow process in iRoom design meetings. Due to the high importance of information in iRoom, the author believes that it can be one of the design/iRoom managers' checkpoints in order to avoid future problems in iRoom meetings.

7.2 Visualization

An important element, which is mentioned in the interviews, is the advantage of having a visual image of a pre-designed site. By using visualization, production site has a better understanding of what is going to be built.

Most of the interviewees considered visualization as an advantage, which has been brought to construction – more specifically to the iRoom design meetings – by using BIM. Although this is proved that visualization is a notion that is deeply rooted in BIM (Azhar et al., 2008; Eastman et al., 2008; Azhar, 2011), visualization is also a part of lean that can support lean construction (Sacks et al., 2009; Salem et al., 2006).

It proves that in the academic context visualization is an integrated notion, which can be investigated considering lean or BIM or both, though in my case, most of the

interviewees considered it as only a BIM advantage. The Author concluded that visualization brought many advantages to the iRoom design meetings that seem to be beneficial for construction companies in the long term. For instance, the possibility of evaluating different design options, better estimation of quantity needed for the production phase and easier planning are some of these advantages which are beneficial for construction companies in both short and long terms.

7.3 Coordination and collaboration

All interviewees mentioned the easier coordination resulting from holding design meetings in iRooms. It is interesting to hear that the coordination issue was noticed by all design managers in the company since one of the aims of using iRooms is having better coordination.

BIM helps the AEC industry to accelerate coordination and collaboration in projects. This increase in collaboration and coordination results in better time management, cost efficiency and increase profitability (BIM). However, it is not the only advantages counted for BIM. In TVD, collaboration is one of the main parts which is highlighted (Tjell, 2010; Ballard 2006). However, collaboration is not a main result of my interviewees but it was noted as compliment to the coordination aspect of the iRoom design meetings. Both collocation and collaboration were mentioned in the interviewees.

7.4 Collocation

The idea of holding design meetings in a collcated room, later named as iRoom, is a core of the iRoom idea. It is both possible to follow the line of collocation advantages in lean and BIM (Tjell, 2010; Ballard, 2006; Schreyer et al., 2005), though it is directly connected to lean and not BIM.

The idea of collocation brings many stakeholders from different organizations in one place. This helps design teams to share their knowledge so ease knowledge/information flow among meetings' participants. However, therea re more advantages mentioed for collocation, it is found in the interviews that interviewees, mostly, considered collocation as a base for defining iRoom meetings and not as an extra advantage of it.

It is worth noting that interviewees noted noise disturbance as an important issue which hinders working in a collocated meeting, though the disadvantages of collocation are not highly focused in literature. Also, the room provided for holding iRoom meetings should be equipped with enough technical equipments since most of the interviewees mentioned lack of technology as a disadvantage to the collocated meetings.

7.5 Communication

Easier communication is another advantage of iRoom design meetings related to the nature of holding design meetings in a big room instead of having separated design meetings. It is worth mentioning that it is not related to the visualization issue but

related to the nature of having a big room that all people from different disciplines can gather and share their knowledge.

In a collocated meeting usually people feel free to communicate and share their ideas compare to the traditional meetings. Nevertheless, the notion of communication is rooted in lean and not BIM (Ballard, 2006; Tjell, 2010; Sacks et al, 2010). Author believes that visualization ease communication among meetings' participant.

7.6 Lean

The awareness of using lean in the company was an interesting issue since there are many articles describing advantages of it in scientific databases. Most of the interviewees were not aware of lean. Only two out of six interviewees have heard something about lean. And only one of them was able to describe its advantages in their project. The other four were not mention it as a main part – better say process - of their routine work.

There are different advantages mentioned for BIM-Lean integration in literature (see for instance, Sacks et al., 2010). There are also some scholars who have studied the BIM-Lean in iRoom design meetings (Khonzade et al., 2005; 2006). However, as mentioned earlier, there are only few studies that discuss the BIM-Lean integration and this research could provide some additional insights in this field.

Based on the study performed and the interview results the study shows that the iRoom concept provides an opportunity to connect BIM and Lean principles with each other during the design phase. Through the concepts of collocation, collaboration, visualization, and by sharing information; a number of Lean concepts are applied within the case study that could support an improvement in productivity, better use of resources and time, and cooordintion and collaboration.

The crucial effect of visualization in the iRoom atmosphere on increasing the productivity is a point that needs more research by scholars and can be an interesting topic for future research. Also, visualization enables the design team to prevent future non value-adding activities and stops unnecessary extra meetings that make the project a leaner project.

Collocation is an element of iRoom design meetings. There are some advantages that are brought to the design meetings because of the collocated nature of the meetings. It was sometimes hard for me to distinguish between these kinds of advantages and the advantages, which are dedicated to the BIM, lean or both of them.

Adding and sharing information in iRoom design meetings is an extremely important element in my research since all of my interviewees highlighted it as a crucial aspect in collocated iRoom design meetings. Although the importance of adding and sharing information in iRooms is mentioned by NIBS (2007) and Van Nederveen et al. (2009), its importance is underestimated in empirical studies. It is worth noting that adding and sharing information have deeply rooted signs in both BIM and lean so it can be investigated from many different aspects.

8 Conclusion

Investigating iRooms, as a very unique way of work in the design phase, and analyzing it according to the BIM and lean aspects, is a tough job due to the unique nature of the subject. There are numerous attitudes towards BIM and also lean; mostly argue that they are practically beneficial in many different aspects for the companies (see for instance, Sacks et al., 2009 and Penttilä, 2006). However, the author believes that talking generally about BIM and lean integration in the design phase would not be that interesting.

In order to investigate the mentioned research question of this thesis, firstly it has been tried to use case study which makes me able to compare the findings from the literature to the findings from my case study. In order to do that one of the biggest construction firms in Sweden was chosen and six interviews conducted with different employees working with iRoom design meetings in their daily works. The next paragraph gives a brief view of BIM and lean and their connection to the iRoom.

As Ohno observed the waste in Toyota, there are some parts which are unnecessary to the workflow. These non value-adding steps only add cost to the customer. Talking about origins of lean, like Ohno's view, reminds the simplicity of considering the end users (Baines et al., 2006). By considering that any kind of process should be considered by answering the simple question of

"Is it a value adding activity or not?"

The author strongly believes that working in an iRoom environment adds value to the customer. In other words, considering the nature of this way of work, the iRoom is a simple symbol of adding value to the product for the customer. My findings from my interviews also prove the mentioned statement about lean and its role.

In the contemporary construction, BIM is an essential part of the work. My observations and interviewees in two different countries – Iran and Sweden – prove this statement. But my research question is different from the new uses of BIM in construction. It is a narrow but unique difference to be remembered in any researches that considers BIM. However, there are numerous advantages counted for BIM (see for instance, Azhar et al., 2008 and Azhar et al., 2011), it is important for me to focus only on its interactions with lean in the iRoom design meetings.

8.1 Answering research question

My main research question is "How can Lean and BIM complement each other in the design phase?" I also have another sub-research question as "in what aspects BIM and lean can complement each other in the design phase?" It has been tried to explore them in different aspects with critical eyes.

As main conclusion of this thesis, I concluded that BIM and lean, as two contemporary ideas of work in construction, have the possibility to integrate and work with each other and with other ways of work. As it noted above, iRoom design meetings are the integration of BIM and lean in many different aspects: however, we

are in the first stages of using them together so in some cases we are not aware of their uses and underestimate their abilities.

Moreover, it has been tried to find the aspects that BIM and lean can complement each other. BIM brought different advantages to the construction (Azhar et al., 2008). My findings prove that the most important of it is the visualization. Visualization is an important aspect in iRoom since it helps the whole design team to focus on only one model instead of looking to different drawings. It fasten communication, increase the communication between team members so have direct effects on collaboration in design phase. Although visualization has deeply rooted lean sides, design teams are able to use visualized plans, visualized quantities and visualized designs by using BIM software as well. Therefore, it has strong connections in BIM and lean sides.

Collocation, communication, adding and sharing information and visualization are the elements that were highlighted by interviewees, however there are strong emphasize on them as academically proved connections between BIM, lean and/or both.

Adding and sharing information is the element that enables team members to have access to the all needed information in a more convenient way. It has crucial effects on easing communications and increase collaboration among team members. The author of this thesis believes, however, that the fact of having better access to the information – that brings many other advantages to the project - is an illustration of lean principals, BIM importantly and strongly enables design teams to add and share information better and better. It is one of the most brilliant integration between BIM and lean. However, its different aspects are not fully investigated yet.

Collocation, communication and collaboration are the interviews mentioned elements of BIM and lean that has some effects on each other as well. It is not only believed that they have signs in BIM and lean but also it is believed that they have some synergetic effects on each other.

8.2 Limitations of the study

It should be highlighted that this thesis focused only on one company as main case study with limited number of interviewees. The author was unable to allocate more time to find more suitable of interviewees due to the short time for doing this thesis. Thus, it is worth mentioning that the reader should have a critical view to findings and avoid generalizing them to all other companies working with the same structure.

Another limitation that was not clear in the first days of conducting interviewees was having interviewees in *English* while all the interviewees use Swedish as the main language for work. Firstly, it made some social challenges in the first part of the interviews till the interviewees feel friendly. Secondly, it caused some of my questions not to be answered directly but in a more unnecessary comprehensive way, which made a few interviews longer than expected.

This study only focused on the design phase and not the whole construction process. This issue should be taken into account in the process of valuing the findings of this thesis. This study has been done as a master thesis focusing on a case study. Due to many limitations, for instance the time pressure for completing the thesis, the author

was only able to focus on the case study only in a short period of time in the design phase.

The study is only limited to the iRoom design meetings and not other types of design meetings. Therefore, it may not be rational to narrow the BIM-Lean advantages/disadvantages to only the mentioned points. On the other hand, generalizing the findings of this study to all types of design meetings – rather than iRoom design meetings – may not be possible and the differences between atmospheres of design meetings should be taken into account.

8.3 Suggestions for future research

There are some issues that harden investigating possibility of integrating BIM and lean. Issues that can act as obstacles in integrating BIM and lean can be as an interesting topic for future researches. However, there are some other points to be highlighted for future researches:

- It is extremely important to define "lean" in the first phases of the research. Lean is one of the broad terms, which can be interpreted in very different aspects.

- BIM and lean idea in the iRoom atmosphere is a unique and new approach for holding design meetings so it is suggested that the findings of later researches to be compared with the earlier. It helps the researchers and industry to have feedbacks on their ways to improve.

- A more practical approach to iRoom can be a very attractive topic for future researches. Due to the undeveloped – and new – nature of iRoom in my case study it was impossible to compare my findings to other researches that have a completely implementation of iRoom.

- It is worth noting that BIM and lean can integrate in different ways. IRoom is only one of the occasions that they can complement each other. So it is suggested that in any research it would be great to define the level of BIM-Lean integration in the very first steps.

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