Mapping between BIM and Lean-Construction

Master thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

Submitted on 25.08.2017 from

Mohamed Gamil

552949

First Supervisor: Prof. Dr.-Ing. Nicole Riediger

. Second Supervisor: Ing. Ammar Al-Saleh

[Acknowledgement]

This Master's thesis research would not have been possible without the involvement and support of many people. At the end of this interesting and at times difficult journey, I would like to express gratitude to everyone who helped me.

I would like to thank my supervisor Professor Nicole Riediger, whose experience and advice helped me enormously throughout writing the thesis, and the study program. I would like to thank Ing. Ammar Al-Saleh for his support and advices during different development phases of the thesis.

I am very grateful for the continuous support and guidance of my Parents; Dr. Mostafa Gamil and Dr. Rockia Gamil, throughout my life and my study.

Mohamed Gamil

23-08-2017 Berlin

Metropolia

htw. Hochschule für Technik und Wirtschaft Berlin University of Applied Sciences

International Master of Science in Construction and Real Estate Management
Joint Study Programme of Metropolia Helsinki and HTW Berlin

date 18. August. 2017

Conceptual Formulation
Master Thesis for Mr. Mohamed Mostafa Gamil
Student number 552949

Topic:
Mapping between BIM and Lean-Construction

The current research aims to explore the benefits of using BIM and Lean-Construction tools in the construction industry. Since the implementation of the new technology (BIM) in the industry, the data exchange and the managing processes are facing a revolution. Meanwhile, the use of lean in the construction industry has become an iconic model for a successful managing technique. The aim of this study is to provide a road map on how to combine the two previously mentioned tools in the construction industry.

Achieving the aim of this study required the following two research methods:

a) Reviewing literature related to both fields.
b) Analysis of case studies where both BIM and Lean are implemented.

Research Questions:

- How BIM and Lean impact the Project (Product, process, Organization)?
- Who from the stakeholders benefit from BIM and Lean?
- How could a roadmap be developed, to integrate BIM and Lean in construction projects?

....

Prof. Dr.-Ing. Nicole Riediger

Abstract

Investigation of BIM and Lean are the main research areas of this thesis. Conducting a review on the literature related in both fields, and analyzing 24 different case-studies are the main research method of this research. This thesis aims to investigate the impact of both approaches (BIM & Lean) on construction projects. Also identifying the benefits of the use of both tools on the project stakeholders. Besides, providing a roadmap for successful implementation of BIM and Lean.

This thesis is structured into Three main sections, the first section is a literature review conducted on AEC Industry, Building Information Modeling (BIM), and Lean philosophy. The Second section is the analysis of case-studies and developing of road map for the implementation of BIM and Lean within the project. The last section of this study is the Conclusion and Recommendations.

This research shows a real correlation between the implementation of BIM and Lean in construction, and the success of the project, and that full awareness of the implementation of BIM in a Lean-environment should be diffused between the project stake holders. This study comes out with 17 different use of BIM and 11 different Lean approaches, which could be adopted in construction projects in order to enhance the efficiency of the project and lessen the waste areas. Moreover, this study proves that all of the project stakeholders get several benefits of using BIM and Lean.

Keywords: Architectural Engineering and Construction (AEC) industry, Building Information Modeling (BIM), Lean-Construction.

Table of Contents

Table of Figures

List of Tabulations

List of Abbreviations

LBS	Location Breakdown Structure
LBM	Location Based Management
LPS	Last planner system
TFV	Transformation flow value
LPDS	Lean Project Delivery System
LCI	Lean Construction Institute
PPC	Percent Plan Complete.
IFC	Industry Foundation Classes
CMMS	Computerized Maintenance Management System
MRP	Material Requirement Planning
NPV	Net Present Value
NCF	Net Cash Flow
FM	Facility Management
IFOA	Integrated Form of Contract
IPD	Integrated Project Delivery
RFI	Requests for Information
LOB	Line-Of-Balance
CPM	Critical Path Method
IFC	Industry Foundation Classes
CAD	Computer Aided Design
2D	Two dimensions: x and y
3D	Three dimensions: x, y and z
4D	A 3D model integrated with a time plan
5D	A 3D model integrated with cost estimation

1. Introduction.

This chapter aims to give an introductory overview of the study that has been made. The problem statement was presented according to the challenges faced by Architectural Engineering and Construction (AEC) industry. Also this chapter include aim, research questions, methodology, and the outline of the thesis.

1.1. Background

The Delivery of successful construction projects is constantly being challenged by virtue of; tight schedule, limited skilled manpower, limited budget, and other waste main areas. Which appear due to the uncertain and fragmented nature of the Architectural Engineering and Construction (AEC) industry [1].

The AEC industry has adopted a lot of techniques to reduce the waste, deliver the project in time and within the budget limit. One of those technique is Building Information Modeling (BIM) [2]. BIM is more than a software for geometrical drawing it is a data management software to define and breakdown the final product into small manageable pieces these small parts are all coming together in a hierarchy to form the project. BIM is described as *"the technology of generating and managing a parametric model of a building"* [3]. It is also described as Object-Oriented-3D-Model which bridge the exchange of information and communication [4]. Furthermore, technology implementation in construction industry is lagging behind in comparison to other industries [5].

Despite the fact that construction industry is facing serval problems, the industry is still seeming to outdo those problems by introducing of effective approaches such as BIM and Lean-Construction. Researchers e.g., Koskela recommended the adoption of Lean tools within

[1] (Sun, et al. 2017)
[2] (Jones and Bernstein 2012).
[3] (Lee, Sacks and Eastman, Specifying parametric building object behavior (BOB) for a building information modeling system 2006).
[4] (Miettinen and Paavola 2014).
[5] (Dave, et al. 2013)

construction projects to improve the efficiency of the projects [6]. Moreover, other researchers in the field also stated the advantage of Lean implementation [7].

1.2. Research Questions

The main research questions are:

- How BIM and Lean impact the Project (Product, process, Organization)?
- Who from the stakeholders benefit from BIM and Lean?
- How could a roadmap be developed, to integrate BIM and Lean in construction projects?

1.3. Research Methodology

Achieving the aim of this study required the use of the following two research methods:

1. Conducting a literature review on Architectural Engineering and Construction (AEC) Industry, Building Information Modeling (BIM), and Lean philosophy, in order to formulate a comprehensive understanding of the research topic.
2. Analysis of 24 different case-studies where both BIM and Lean were implemented, as results and impacts which were recorded in one project cannot be generalized. The choice of the case-studies depended mainly on the successful implementation of BIM and Lean-construction tools. Moreover, during the choice of the case-studies main focus was laid on having different cases from different countries, different companies (as culture plays a critical role when it comes to management and anything which is related to people behavior).

[6] (Koskela and others, An exploration towards a production theory and its application to construction 2000)
[7] (Dave, et al. 2013)

2. Architectural Engineering and Construction (AEC) Industry

2.1. Contract

This chapter will discuss the contract in the construction industry and it will go throw three of the main contractual type in the industry, as contract type has big impact on the project technology and management method also on the culture of the project management and how the project stakeholders manage the relation in between, and which party is retaining the risk and which party is passing it away, also contract do affect the flow of the information between the stakeholders. This chapter will demonstrate four of the famous contracts and the uses of them.

2.1.1. Design-Bid-Build (DBB)

Design-Bid-Build is the most used contractual approach worldwide as almost 90 percent of public building and 40 percent of privet buildings are following this approach in doing the contract of the construction process [8]. What is really astonishing in this survey is that the percentage of the public building which follow this contractual approach is higher than the one at the privet sector, that can be explained by the less of political pressure on the contractual process, as the design bid build process is seeking the find of the most cheapest bid for the construction process. One of the main benefits of the (DBB) approach is providing a competitive approach for finding the contract in the execution phase.

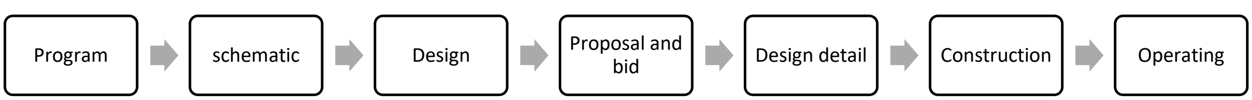


Figure 1 - DBB Process

As shown in Figure 1 the Design-Bid-Build process is totally linear relation waiting for the finish of the previous step to start the next step. Usually this process is done in that sequence that the clients hire an architect to do the design and the architect may ask for a help of consultant to do the special designs on his behalf like the structural design and HVAC design, afterwards the architect provide the client with the document which the client uses to go into open bid processes

[8] (Guy 2007) p. 1-7

and the selection of the contractor is depending on the low cost and some technical requirements, and the main contractor is doing almost the same to choose the subcontractor. What was document is *"every contractor going into bidding process is spending around 1 % of the project cost on the preparation of the bid and this contractor go into from 6 to 10 bids to have one which lead by the end an increase in the cost for every project by 6 to 10 percent of this project main budget"* [9] after the winning contractor have the contract and receive of the project drawing the winning contract start to redraw the drawings to suit the construction process that is called arrangement drawings, and then the main contractor passing this drawings to the subcontractor and the fabricator who also start to do some detailed drawing to help in the fabrication processes.

Usually after the starting of the construction processes a lot of information needed to be cleared e.g. Requesting for Information (RFI), and a lot of change order are happened, my experience dedicates me to mention "some contractors provide a bonus for any engineer who make a change order for the project as the change order is making more profit and providing more time to the contractor" all of that type of change order and RFIs is result of the ignorance of the designer about the whole circumstances of the construction process, the client requirements are changed, some material is no longer available in the market, new technology is used in the construction process. All of those items and more lead to extend the time and the budget of the project.

2.1.2. Design Build (DB)

Design Build (DB) is other main face of contracts in the AEC industry as this type of contract has shown a lot of success in the last few years and it is continuing to improve and expand in the industry. this type of contract starts when the client goes to the DB team and ask for construction of a new building the client try to express his requirements and then the DB team start to develop construction model and provide the client with the project budget and project timeframe, then after agreeing on everything regarding the time and the building specification and the design the DB team take the project as a Lump Sum.

[9] (Ling, et al. 2004) p. 75-83.

The Design Build process reduce the degree of freedom of the client in doing changes to the project during the construction phase, and also reduce the risk on the client which is related to design and construction. All the risk is on the project team to deliver the project in time and within budget. This type of contract enhance the use of BIM [10] as a new technology for data and communication throw the project and while developing the design of the project as the design is not developed totally in one phase but the design is keep developing during the whole construction process, as the construction go further the more details is added to the construction drawing to come a long with the current circumstances of the construction site. That mean the project is totally an output of a collaboration between the designer and the contractor there is no place for we and them [3].

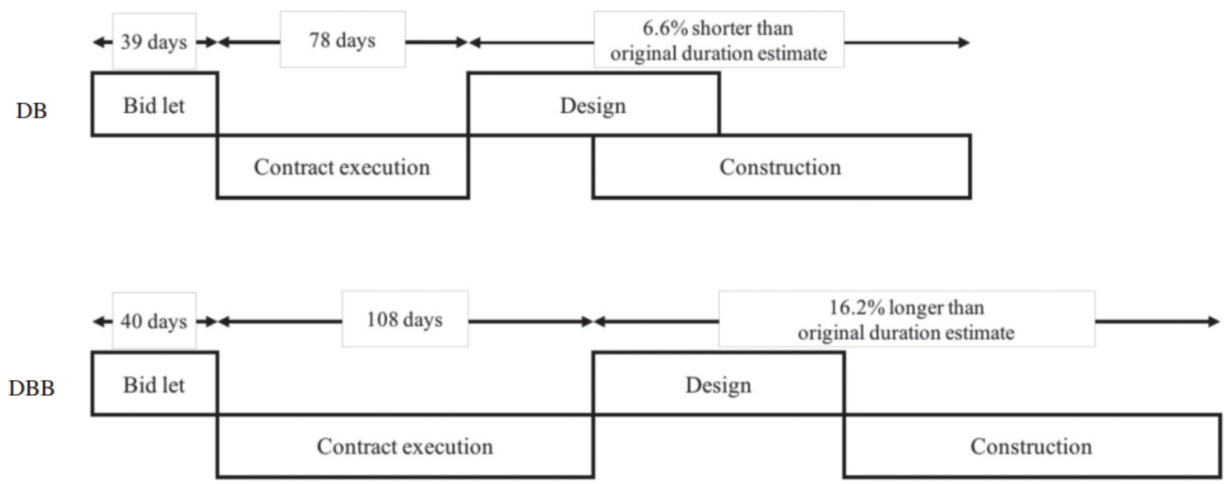


Figure 2 - Comparison between DB and DBB in the transportaion sector in USA

In terms of time saving during the project a study was carried out to demonstrate the differences in terms of time between the DBB and the DB on the transportation projects on the USA and this study concluded as shown in Figure 2 [11] that the duration in the DB project is fare shorter than it in the DBB all of that is due to the reduction in waiting time for the completion of the design to allow the construction to start, the reduction in the number of changing orders and the requesting of information, reducing the uncertainty level related to the project. Besides that, in the DB the required time to execute the contract is shorter than it in the DBB and the Biding time

[10] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) p.7.
[11] (Park and Kwak 2017)

is also shorter. All of that lead to a rapid increase in the implementation of the DB contract than the traditional DBB.

2.1.3. Construction Management at Risk

For this type of contract the owner hires a construction manager on board from the early phase of the design of the project to provide the designer with advices regarding the constructability of the design and to make the design more reliable, and also the use of the construction manager could be extended to the preparation of bedding document and cost estimation and providing some schedule and value engineering to the project, as hiring the construction manager at an early phase of the project reduce the level of uncertainty which is related to the project by providing the advice and consultation to the design team. And also results in generating more reliable bedding documents, besides the reduction for the number of RFI and changing order in comparing to the normal DBB [12].

2.1.4. Integrated Project Delivery

Integrated project delivery is a similar way of contract of DB with a slightly differences on the risk shearing, as it was mentioned before the shearing of the risk in DB is on the DB-team side and the client do not have to shear any type of risk after signing of the contract, however in Integrated Project Delivery method the risk is sheared by the whole team (client, designer, and the contract). Sequence of implementing IPD-method is the client participates in developing the conceptual drawing and form or fix the estimated budget and set the main targets of the project, besides providing the designer with his view of the project. Then the client passes his idea to the designer who start to develop the drawing to fit the client desire and go along with the estimated budget which was established earlier by the client, meanwhile the contractor starts on the execution process while the designer is developing the design, the target of the contractor is to deliver the project with the target quality within the estimated timeframe and under budget. Bonus mauls system is applied to the project. When the project is delivered under budget the contractor and the

[12] (Miller, et al. 2000) p. 58-67.

designer get bonus, and when the project is delivered over budget the contractor and the designer receive a deduction (sharing the hard time and the good time) that way in contractual is growing right now in a lot of countries and even some industry stakeholders is expecting this method will overtake the DB method [13]. This type of contract need a good and continues communication environment to be established successfully and also require a transparent environment, besides establish a bridges of the trust between all of the project stakeholders to deliver the project. For this type of contract BIM is an innovation tool for communication in order to deliver the ideas clear between all the project parties. This type of contract is also the main family of other types of contract like the Relational contract or the Alliance contract, or Integrated Form of Agreement.

2.2.Waste in Construction Industry

This section will discuss the waste in construction industry and the main roots of it, as it is known construction industry is one of the biggest industry in the world which has a lot of rooted waste, and while the productivity of the other industry is going up the productivity in construction industry is the same and may be going down, all of that is due to the lake of efficient application of the new automation tools besides the waste which is rooted into the industry and start to move form a project to the other caring it the staff working team. According to my experience in the construction industry waste in construction industry is like a virus spreading into the construction project and the carrying bodies of this virus is the people working in the project.

Waste roots in construction industry can be broken down into three main areas: process related, technology related, and policy related limitations [14]. Process is about the technique and the sequence of work also it is about how to integrate all the available resources to get the optimal use of it, a process is a specific ordering of work activities across time and place, with identified input and output [15], process is about the flow the more flow maintained the more output gained, in order to achieve the more flow the main focus should be on the constraints which reduce or stop the flow. *"Technology is the application of scientific knowledge to practical tasks by organizations that involve people and machines, it is about the interaction between software, hardware and*

[13] (Kent and Becerik-Gerber 2010) p. 815-825.
[14] (Won and Cheng 2017) p. 3-18.
[15] (Hammer 1990) p. 104-112.

human been in the planning, design and demolish phase" [6], types of technology which can be used in the construction industry are countless, starting from the simple excel sheet to do the quantities calculation and going to BIM and the most developed software of visualizations. Policies are the rules for providing a good working environment it includes also education, contracts, regulations, standards, and guidelines [16], policies also is about the norms which is applied in the country and the roles to follow, the project could not only be affected by the internal policies but also by the external policies, as a matter of fact the project is done to take a part of the surrounding environment in the future which mean the project need to have a kind of interaction between it and the surrounding environment.

2.2.1. Main Areas of Waste in AEC

1. **Waste due to poor procurement & planning.**

This type of waste is the most common and it can be caused by inaccurate quantities take off as it was documented *"around 1.6%of the total amount of Ready Mix-Concrete ended up as a waste"* [17]. There is no right and wrong plan or right and wrong schedule, but there is bad, good, and better. Scheduling and planning is playing a big role in the rote of waste as the managing of buffer and the sequence of the activities and the calculation of productivity from the really beginning phase of the project, all of that playing a big role in doing the forecast of the waste earlier and once the forecasting is done a proactive action plan list could be deployed. Furthermore, poor procurement and planning can end with a long storage period which is causing additional cost and in some cases it could lead to damage of some material e.g. Cement & chemicals. BIM & Location-Based-Management were examined in this area and were showing a lot of strength in calculating the quantities for the construction and also play a crucial role in generating just-in-time procurement schedule. Moreover, the method of material and resources transportation within the site and from the supplier to the site lead to a big waste in time as it was recommended the material to be touched twice one time at the supplier and the second during the insulation.

[16] (Succar, Building information modelling framework: A research and delivery foundation for industry stakeholders 2009) p. 357-375.
[17] (atz and Baum 2011): 353-358.

2. **Waste caused by changing in design and poor design management.**

change orders in construction project is always unsolved problem till now it was estimated that change orders might lead to up to 33% of the construction waste [18]. Besides clashes due to poor communication between different disciplines in the project (Architectures, engineers & MEP). Implementing BIM in construction project lead to reduction of the number of change orders. For example, Williams [19] has observed that around 47% of the waste induced due to the number of changing orders in MEP was reduced through BIM design validation, changing order in construction industry has more than one root of cause. One is by the client himself that the client cannot express himself clearly form the beginning of the project (and here comes the role of the architect who should help the client to paint a whole picture about his needs, and also with the help of visualizations software the client could derive his idea smoothly), other cause is the unavailability of the material in the market, that is really common and specially if the designer does not has a deep view on the construction market that could also be solved by going to DB contract or IPD or by hiring a construction manager during the design phase of the project. Lack in the communication and collaboration between the design stakeholders and the execution team which lead to a lot of clashes either hard clashes or the design has some parts or specification which is impossible to be done in the current circumstances of the project.

3. **Lack of prefabrication and standardization due to inaccurate dimensions in design early stage [20].**

most of the construction industry use traditional way of construction like cast-in-place concrete which has noticed to be a source of a big waste, e.g. Lawton et al. [21] documented that 70% reduction in concrete waste throw prefabrication. Jaillon et al. [22]have also observed and documented a reduction of 52% of overall construction waste volume could be achieved through using prefabrication elements in construction. Many studies also have reported that there is a lack of prefabrication in construction industry due to inaccuracy

[18] (Osmani, Glass and Price 2008) p. 1147-1158.
[19] (Williams, Building-information Modeling Improves Efficiency, Reduces Need for Changes 2011).
[20] (Won and Cheng 2017) p. 3-18.
[21] (Lawton, Moore, et al., The gammon skanska construction system 2002).
[22] (Jaillon, Poon and Chiang, Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong 2009): 309-320.

of the dimensions of elements, that during the design the dimension of the element and the space between elements have some clashes and some of this clashes cannot be discovered until the execution phase, which lead to a risk of using precast or prefabricated elements. However, BIM can be used now a day to overcome inaccurate dimension as a matter of fact BIM is 3D model which will offer better visualization of the project a long side proper element dimensions, moreover BIM is used now a day in shop drawing. Furthermore, BIM is very efficient in scheduling and managing the process of prefabrication elements.

4. **Waste due to double material handling.**

double material handling and inappropriate materials, is one of the main area of waste in construction industry however a lot of studies were carried out to reduce the amount of double material handling [23]. However, integrating BIM and lean concepts have a good potential to minimize the waste in this area, as BIM will help in making a good visual monitoring and control on the whole site by providing the project team with the option of viewing the whole layout of the site to determine the storage area and the material transportation on site, furthermore BIM also provide the project team with a visualized detailed schedule of the material handling system. On the other hand, adopting lean concepts (e.g. Just-In-Time will reduce the storage space and also double handling, besides using Pull concept not Push as it helps to use the buffer in proper way and also helps in material delivery system).

5. **Inadequate construction waste management on site.**

inadequate construction waste management includes, lack of tracking of construction waste movement, inappropriate space planning for construction waste, inappropriate planning for material storage space, and delayed on-site waste sorting [24]. This process cannot be improved by only implementing BIM or adopting any theory but it needs to establish tracking waste culture in the project starting from the project managers and ending with the last one in the project hierarchy.

[23] (Exploring critical success factors for waste management in construction projects of China 2010) p. 201-208.
[24] (Analysis of the implementation of effective waste management practices in construction projects and sites 2014) p. 99-111.

6. **Poor of communication.**

this point go into different levels starting from poor communication between stake holders as it was noticed in many construction project and one of the ever and most problem in construction industry or any other industry is communication but when looking into deep in construction industry it was noticed that there is a poor communication between project stakeholders, or passive participation of the project stakeholders which has a harming effect on the project waste management [25], poor communication between project members and also poor representation of their ideas what also was documented in some cases there is a passive representation; lack of coordination and reviewing meetings [26] not all of the people who are supposed to participate in the project and were represented in the waste management plan are welling to have an effective participation some of them consider it more or less as a routine meeting.

2.2.2. Production-Theory-Based-Metaphysics

Production according to metaphysics theory is a transformation-flow-value (TFV), as it was investigated production is a change occurs to the matter (material, resource, etc.) during a time interval towards an output (production target to meet the value of the customer). There are two theory of Production, the first is (Production is a flow of time and space of material towards the output) which is named the flow model and the second is named value generation model which define production as (Production is conversion of a particular customer's requirements into products which fulfil them) [27].

What was investigated and documented by (Koskela et,al 2007) that production is transformation flow value TFV and it is based on metaphysics as it was explained, that in any transformation process is metaphysics process and is framed by input, output and time frame to accomplished it. It was also explained earlier production theory is divided into two areas one theory

---

[25] (Wang, Yuan, et al., Critical success factors for on-site sorting of construction waste: a China study 2010) p. 931-936.
[26] (Formoso, Soibelman, et al., Material waste in building industry: main causes and prevention 2002)): 316-325.
[27] Koskela, L. and Kagioglou, M. (2005) On the Metaphysics of Production. 13th Annual International Group for Lean Construction Conference – IGLC. Sydney, Australia.

is subscribed to (the thing metaphysics) which could be given the name $(TFV)^t$ when t is referring to the thing. This theory deal with the production process as an output and input in other words (command and control or managed as planned) that it deals with the management as an activity which occurs at the beginning of the project. During this time zone the project is planed and reviewed to be feasible and applicable to accomplish its goal, and that what is called push system.

Push system is based on some assumption: 1.1. Task and the decomposed tasks are black boxes with an assumption that this black box should be assigned to someone to execute it, 1.2. Tasks are similar in the way of managerial principles, 1.3. Tasks are independent, 1.4. Centralized management,1. 5. Management is a discourteous task, 1.6. Fixed objective (get-the-task-done).

The second theory is subscribed to (the process metaphysics) and was given the name $(TFV)^p$ when p is pointing to Process, which could be named also pull theory or management as organized for this theory.

Pull system techniques: 2.1. Tasks are still black box but for this black box it should be assigned the skills technology and resource which will be a part of execution of the task, 2.2. Management is a continues task, 2.3. Management is not centralized but everyone should take a part in the management, 2.4. Tasks are not independent but it has a lot of interdependency, 2.5. Tasks are not similar but every task has to be managed and control with different way depending on the nature of the task [28].

2.2.3. Flow in The Construction Process (Construction Physiscs)

Flow in production process is the backbone to link everything with different manner to pave the road between the input and the output, and to understand the flow we a deep look on the ways to represent it in planning from the management prospective is requiered. There are several ways to represent flow and most of them are very old and used for long time ago the most common ways to view the flow are: 1. Critical-Path-Method (CPM) this method is really simple in data and flow representation as represent the task in a box with its duration and start finish dates and the link between them using arrow method to link them, 2. Gantt Chart which represent the task with a line drown on a grid versus time but it makes it really difficult to visualize the relation between different tasks, 3. The Line-Of-Balance (LOB) it is the most sophisticated tool between this three

[28] (Koskela, Rooke, et al. 2007).

tools asit is possible to view the productivity of the task and also to visualize the resource corresponding to this task and also the dependencies can be viewed.

Even so this model is the most used, nevertheless in the most sophisticated tool (LOB) is still dealing with the task as an isolated island with its resource and material but does not take the other external factors into account. There are two big asspects; process flow and operation flow [29], process flow is the flow of the project between the input and the output, on the other hand operation flow represent any work done. It can be visualized as a river (indicated the process flow) this river has a lot of roots attached to it this roots are (production flows). This river model has a lot of defects but it can be good for just visualization of the flow. As task has seven precondition to sound like a task and to can be handled: construction design (information), material, workers, equipment, space, connection (predecessors and successor), and external conditions [30].

To achieve the success of the process and the project over all the critical flow should be achieved which can be defined as every factor of this seven above should be meet in the prober time to generate the operation which will happen in defiant place in a defiant time to contribute in the whole process flow and that require form the management continues forecasting to remove the obstructs, which lead by the end of the day of using of last planner system (LPS) and look ahead plan [31].

[29] (dos Santos 1999).
[30] (Koskela and others, An exploration towards a production theory and its application to construction 2000).
[31] (Bertelsen, et al. 2007).

3. Building Information Modeling (BIM)

3.1.Intoduction

In this section the theories and ideas of BIM will be discussed in order to form a deep understanding about BIM and its function in AEC industry besides the challenging of implementing it. Starting from the history of BIM going throw the driving forces behind BIM, and the potential of the using of BIM, and how BIM will add value to the project. Besides the different shapes of BIM which can be shaped into in order to deliver the project. And how to use of BIM as a tool to deliver the final product not as a burden which lead to deviate the project from its main target, and keep focusing on how to implement BIM, and how to structure the work to serve the implementation of the BIM, rather how to use the BIM as a bridge to deliver the final product faster with less waste. During this chapter there will be no focusing on any special software, nevertheless some picture form some software will be used after providing the copyrights just for the illustration of the discussed point.

3.2.History of BIM

The construction industry on of the oldest industries on earth it is related to the existing of the human been to provide a shelter from the environment, this industry kept improving. But for long time the most used way for the communication and data exchange in the construction projects is the linear way of data exchange, nonetheless the data exchange during the construction processes is done periodically and without any rule to govern it, may be the model or the data needed to be changed more than seven times to meet the right decision [32].

The idea of having BIM and generating of a model with different, interrelated, and compatible views is originally introduced by professor Chuck Eastman for more than four decades ago and he named it “Design Description System” this system could be defined according to (Eastman in 1975) as *“Any change of arrangement would have to be made only once for all future*

[32] (Ballard and Koskela, On the agenda of design management research 1998).

drawings to be updated. All drawings derived from the same arrangement of elements would automatically be consistent"[33] this and beside some software developers ideas of understanding this concept is the foundation of what we call it today BIM, the devolvement of idea went further form the geometric linking of different views in order to maintain the compatibility of the model, to the linking of the data into the elements and the objects e.g. (linking the material data to the objects and the procurement data, schedule and cost data, etc.). All of that formed the evolutionary BIM which is used nowadays. Which was introduces at this shape in the 2000s with the idea of adding the data to the model and the use of the computer to provide the help in visualization and keeping track with the work [34].

BIM is now more than software it is a culture, collaboration, and Team working. Adopting BIM as a software in the industry will not push the industry forward, rather it will be a big catastrophe for the project, as it stated by (Hardin, Brad, and Dave McCool) *"BIM is 10 percent technology and 90 percent sociology"* [35] and according to the same resources BIM culture should be maintained in the project before adopting the cutting edge technology.

3.2.1. The Need of BIM

Construction project is very complex, unique, and a lot of parties are involved in the process, besides the big flow of information in the processes. One research conducted by the company Tardif, Murray & Associates (construction company from Canada) shows a good example of the complexity of the traditional industry practice in large projects. Counting the number of participants and documents in one of their projects they ended up with 420 participant companies (including all suppliers and sub-contractors), 850 participant individuals, 50 types of documents generated which total up 56.000 pages [36]. Such compellability will make it really hard to monitor and control the processes and it will make it really harder in terms of the flow of the information, and the requesting for the information. There was an indeed need for a tool to manage this enormous amount of information and sort it in a way to have the proper output of it. And also the need for a tool to enhance the communication between this big number of stakeholders in the

[33] (C. Eastman 1975).
[34] (Volk, Stengel and Schultmann 2014):109–27
[35] (Hardin and McCool 2015). P. 7.
[36] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011).

construction industry. The success of the project counts on having the right information in the proper time to meet the right decision.

3.3.BIM in Constrction Industry

No one could argue that BIM has become a key player in construction industry. As construction industry in the last few years has noticed a sudden development in the way and technique of construction like using prefabricated elements and more innovative material like carbon fiber or at the level of machinery. But meanwhile construction industry still untill now poor in the way of implementing BIM and using more of its feature for the planning of the construction and the site planning. As shown in Figure 3 [37] the rise in adoption of BIM in various countries.

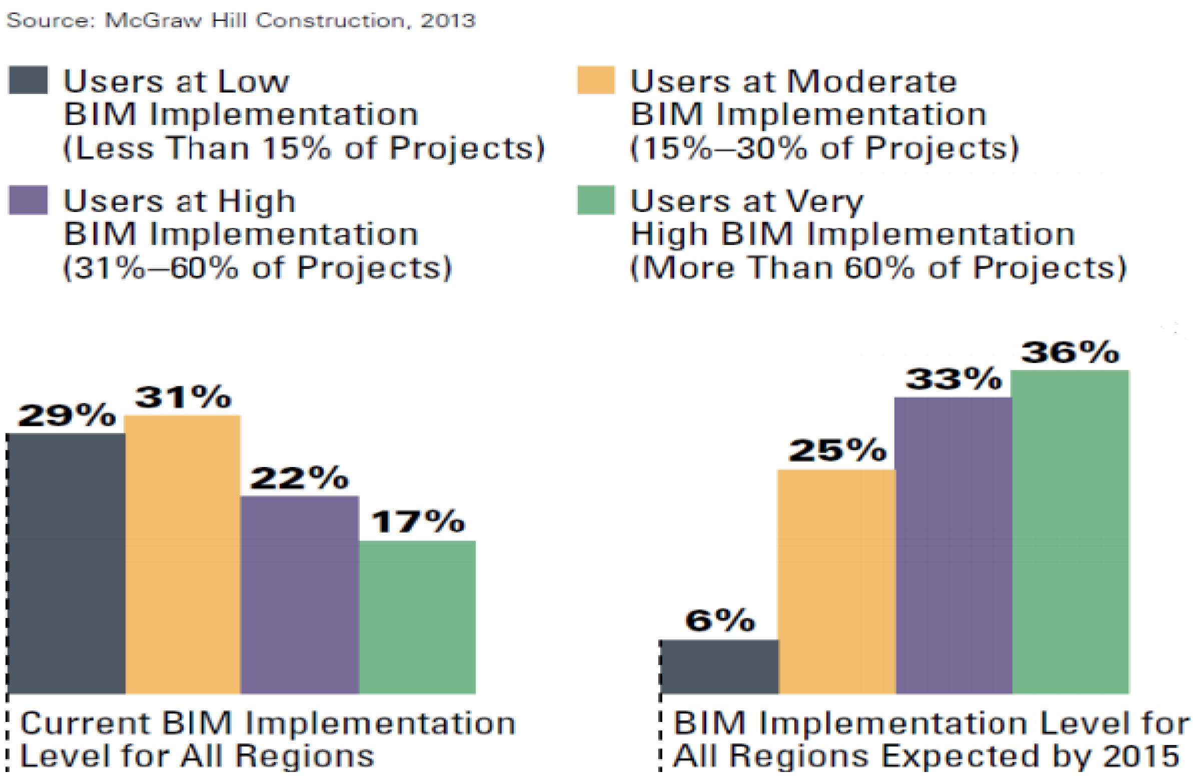


Figure 3 - adoption of BIM in various countries

As the construction industry known with high level of information and high level of detail. And as a matter of fact that construction process is unique and complex industry, besides the high level of communication required to carry out the construction work. BIM is now defined as an eco-

[37] (S. Jones 2014)S.

system for information and challenging tool for communication. But information is not everything, no one could argue on the importunateness of the information, but as Harper & Row stated the fog of too much information can drive out knowledge [38]. Which mean too much information can initiate a new risk which is diluting the main target of our project by focusing on the information gathering and the analysis of it. The using of BIM enhances the process for the construction in two main areas one area is social one by creating the engagement for every team member in the process and the planning of the process and also give the involved people the right to view and edit the information on the model. On the other hand, the physical feature of BIM as it is used to mitigate risk by visualization tool, clash detection, linking the material to the drawing, linking the construction data as schedule to the drawing which is defined as 4D BIM, linking the delivery data and the prices to the drawing, linking the cost data to the drawing 5D BIM, also linking the maintenance data and life cycle analysis data to the model which used for facility management purpose and named as 6D BIM.

This research will cast the light on the using of BIM in the construction phase and how BIM could be helpful during the construction, preconstruction, and handing over phase for the purpose of reducing the waste and to make the industry leaner. Using of BIM during construction could be divided to scheduling where BIM software can be integrated with the lean scheduling methods, e.g. integrating Location-Based-Management to the model as long as Advanced-Work-Packaging-System with the model. Also for logistic with the help of new technology of apple watch and GPS system it is now applicable to link geographical data also to the model which is a big topic linking GIS to BIM. Moreover, BIM is used to link the safety data to the model beside linking the risk data to the construction phases and to the models which help the users in viewing of this data all in one plate form and in a very early stage to help in mitigating the risk, and design the safety to the way which the project is constructed [39].

According to (BIM Handbook P.269) BIM is an intelligent tool for information in terms of management, analysis, and shearing. And the use of BIM in construction information could be divided into five areas according to the same resource (1. *Detailed building information* can be represented in the 3D building model which support viewing the building component with the ability to extract the element geometric information and quantity, 2. *Temporary component* give

[38] (Boorstin 1978).
[39] (Hardin and McCool 2015).

the ability of the model to show and represent the element which is needed for the construction work like formwork and other machinery elements which is involved in the construction process, 3. *Specification information associated with each building component* provide the users with the information related to each element of the project regarding the material and the sequence of work and construction method, besides the information needed to do the procurement of the material associated with the object, 4. *Analysis data related to performance levels and project requirement* data related to the performance of the element like maximum moment and shear force beside type of connections, the load used for heating and cooling system for design of HVAC, and all of data from that kind, 5. *Design and construction statue* of each component to help the users in tracking of each component and providing the users with information related to the statue of the element and the percentage of completion of the trade) [40].

3.3.1. BIM Support Clash Dtection.

For long time ago clash detection was done manually by putting different 2D drawing on the same table and comparing it for any clashes, this process was very long and time consuming, with a lot of miss in the geometry, meanwhile other tool was developed for some contractor and big engineering companies they developed some programs to serve their own need by comparing the CAD drawing together, this tool was at this time helpful but it was not accurate as it was hard for this tool to detect clashes between the drawing lines. In the same time the drawing tools was not sophisticated enough to draw all the model in the form of objects.

The age of BIM, new technology was announced to form a new era of technology used to support the construction. And this tool is developed to help in the way of detecting clashes as clashes was divided into two main areas: *1. Soft clash,* this term mean clearance between object some objects are close to each other in the way that it might be a mistake in the design itself or in the way to make it hard and sometime impossible to be constructed. *2. Hard Clash,* this term means overlapping between two or more objects, or one object is occupying the other one space. Also this tool is designed in the way to give the possibility for searching for specific clearness between

[40] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) P.269.

two objects in the model. Nowadays most of BIM tools support a clash detection feature for checking the model during the design, meanwhile there are some software which is specialized in clash detection like Solibri & Naviswork this software are used mainly from the side of contractor to check the model because the model from the contractor side has a lots of drawing with different extensions.

3.3.2. BIM Support Quantities Take off and Cost Estimation

For long time a lot of tools have been developed to leverage the construction drawing in terms of quantities take off but most of them were manually used. With the rise of BIM, a new era in quantities take off was declared. The quantities will be able to be extracted automatically at any stage of the design. In the preliminary stage quantities data is important in taking the decision of either to proceed with the current situation or should value engineering be applied to cut off some quantities and may be quality. But at this stage the full detailed model is not completed to do that, nevertheless some techniques are used to leverage the quantities take off like by knowing the space of each room and the dimensions of the building some roughly estimation could be done based on the experience and the data of other projects which have had closer situation. As the design goes to be developed more the more details are applied to the model which mean the more accurate quantities take off could be provided from the model, meanwhile BIM support easy and accurate quantities take off at every stage of the project progress and at any time during the design.

Cost estimation process is usually the next step after quantities take off and according to (BIM Handbook P.277) no BIM tool provides the full capabilities of spreadsheet or estimating package [41], and according to the same resource there are three options for cost estimation, *1. Exporting the quantities to estimating software,* this approach is done by extracting the data from the BIM plat form and import it to external software to complete the cost estimation, and it was

[41] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) P.277.

documented that the MS Excel is the most commonly used estimation tool [42]. *2. Directly link BIM components to estimating software*, this approach is done by using some software tools for cost

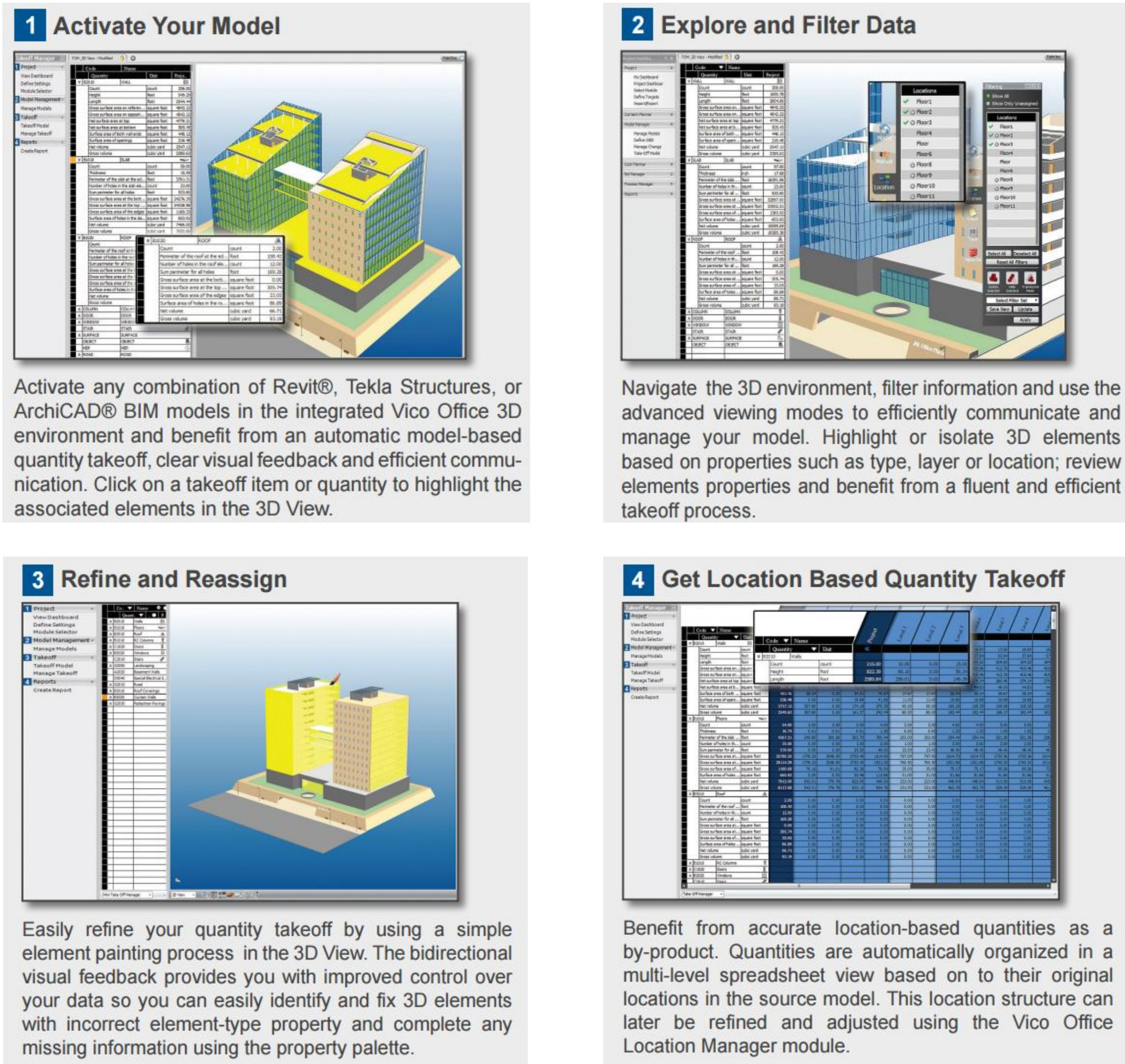


Figure 4 Vico Takeoff Manager

estimation and link it to the model using plug-ins or third-party software, meanwhile there are variety of software which have some plug-ins to support this transition process. *3. Use Quantity takeoff tool*, this approach is done by exporting the model to another BIM platform which support quantities takeoff like CostX or Vico Takeoff Manager, this tools are designed for quantity takeoff

[42] (SAWYER and GROGAN 2002).

and to do that professionally [43] , figure 4 [44] is demonstrating a process sequence for Vico takeoff manager.

3.3.3. BIM Support Construction Analysis and Planning

For long time a lot of tools and techniques have been developed to leverage the analysis and the planning of the construction process, starting from the bar chart method which was really hard to identify the critical path(s) at this time going throw Critical Path Method (CPM). Nonetheless, all of this tools need an expert to understand it and to define the logic for the sequence of the work and the dependencies, which make it harder for the project stakeholders to understand it. Meanwhile, the less visualization of those tools mad a big room for error and failure of the work. Most of 4-D BIM is offering such tools to link the construction elements to the scheduling phase or the due time, some of them doing it internal with a tools embedded in the software itself and other BIM platforms act like a link between the 3D model and the schedules software like MS-project or Primavera. But by the end of the day meaning of 4D model is linking the elements to the schedule by adding the time as a new dimension, which helps in visualization and communication between the stake holders. Long side with the ability to plan the work site layout and deciding the proper space for storage and the location of the Cranes. This tool could go further to be used to manage the transportation in the construction site like material delivery methods from the supplier to the insulation place, going throw the storage and all of that stages. As it was documented in the construction of the empire state building that they used innovative way for transportation of material they have had a new theory for material delivery this theory state that the material will be touched by human been twice once at the suppliers and the second time is during the construction of this material [45] . By linking the object to the schedule the 4D model is generated and ready to use, but also BIM support devising the object to more than one object depending on the sequence of the work like for pouring of a slab it might be not possible to do it in one day then it will be divide into two or more work packages this work package will be carried out in different time intervals. Beside BIM support to assign more than one activity to the same

[43] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011). P.277-278.
[44] (Vico Office Takeoff Manager™ 2017).
[45] (Willis and Friedman 1998) P21.

object like construction of a wall there are many activities are involved in the wall like blokes, steel struts, plaster, painting, and so on. BIM give the possibility to assign more than one activity to the same object and linking them together.

3.3.4. BIM Support Cost and Schedule Control and Management

For long time site control and monitoring is playing a crucial role in the success of the project, and many tools were used to do control on site, BIM provide the project team with a lot of features to do the control this tools could be grouped and summarized according to (BIM Handbook 2011) into, 1. Monitoring of the cost variance, with the help of BIM features in some software like Vico it is easy now to reflect the current statues of the project on the model and compare it with the planned prices to compare how fare is achieved, to how fare is the project from the planned budget. 2. Achievement in the project, also that could be done on the BIM platform to know what is the current statues of the model objects is it in the procurement stage or is it now in the construction and what is the percentage of the achievement. Most of the BIM software provide the users now with a lot of tools to visualize the achievement like grouping color. 3. Purchasing statues, most of the BIM platforms have a procurement planning tool to plan the procurement and give the user alerts of the time to make order for this material or object and the due time for it to be on site, beside nowadays a lot of suppliers have developed some plug-ins which work on the BIM software to support the model with some data about the material specification for this supplier and the price list. Moreover, the tracking of the delivery could be done using the GPS tools like I-watch to know where is the delivery. 4. Health and Safety, BIM support a lot of tools to manage the safety issue in site by marking the dangerous area on the model and also in some cases at specific time in the project some heavy work is being carried out this work make the surrounding area is very dangerous for other workers that could be visualized from the model [46].

[46] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) P.293-294.

3.4.Benefit and Barriers of Implementing BIM

BIM as any application or technology need to be assigned to get to know what is the strength and the weakness of this technology in order to achieve the prober use of it. At this section a survey was conducted on the published papers and the books in the field of BIM in order to gather the big amount of information to list the benefits and challenges of the BIM.

3.4.1. Benefits of BIM

1. **Technical Supporting Tool for The Project Team.**

    For long time even after the generalization of some software which is used to produce the project drawing smarter and more intelligent than before, it remains a big gap in defining the objects on the drawing as every object is the same (every object is a solid line) and the characteristic of the objects needed to be entered manually in a spate box or in attached document to the drawing to clarify the drawing. Which lead by the end of the design to a lot of documentation (which increase the opportunity of misunderstanding and miscommunication). BIM is more than a software for drawing it is a data management software to define the and breakdown the final product into small manageable pieces this small parts are all coming together in a hierarchy to form the project, BIM was described as *"the technology of generating and managing a parametric model of a building"* [47]. It was also described as Object-Oriented-3D-Model which bridge the exchange of information and communication [48].

    BIM also is acting like a general platform to the exchange of data, as a matter of fact BIM is database software, it made it easier to do the data exchange between BIM software and different classes software like Enterprise Resource Planning (ERP) systems as BIM support the feature of developing plug-ins with different languages like C# and python, also BIM support and facilitate the exchange of data between the same BIM

[47] (Lee, Sacks and Eastman, Specifying parametric building object behavior (BOB) for a building information modeling system 2006).
[48] (Miettinen and Paavola 2014).

software which has different producers by using the general BIM communication language Industry Foundation Classes (IFC). BIM support special visualization for the project during the whole lifecycle phase, and also during the design as it supports the navigation throw the model parts to explore and give the feeling of the final product after the construction. As that also helps the client to make the decision regarding some geometric information and material to meet the target use of the building, and also visualization during the life cycle in the planning and operation period.

2. **Knowledge Support to The Users.**

   From the state of art of BIM which state for Building Information Modeling. BIM is used to manage the data within the model platform which help the users to define and visualize the connection between different element, the location, material, geographical information of the building and objects, calculating the U-value for the building, doing the analysis of the firefighting of the building, supporting also some structure analysis, producing the shop drawing automatically of the element with a high accuracy, helping in detecting the clashes between the different BIM models, even it has the option of supporting the users to define their own rule set to the model, In the event of design changes BIM tools can integrate and systematize changes with the design principles, intent and design 'layers' for the facility/project [49].

3. **Support Standardization in The Industry.**

   BIM uses Industry Foundation Classes (IFC) *"a neutral and open specification that is not controlled by a single vendor or group of vendors"* [50] as a slandered language between various software to enhance the commination, the data exchange, and operation on the same model on different software e.g. modeling the 3D on Revit, making the clash detection on Solibri, generating the 4D model on Vico, and adding the cost information on CostX. All of that was easy nowadays with the help of BuildingSmart, that model is now in continuous improvement to assign the full data of the vendor to the model like the prices and the specification of the elements and the location of the vendor even the transportation.

4. **Economic Benefits.**

[49] (Azhar 2011).
[50] (Solutions 2002).

some researches where carried out on the economic feasibility of the using of BIM and the Return of the Investment (ROI) of BIM and it was documented that BIM has a good impact on saving a lot of money of the project by preventing, or reducing dramatically the delay of the projects. Also by the use of clash detection and doing the analysis of the building in different phases and meeting the right decision from the first shot [51]. BIM also play a crucial role in the economic feasibility studies of the building because of the easy method to link the cost to the drawings, and for helping the clients to take the decision regarding the geometry and some important details of the building [52].

5. **Planning and Scheduling During the Life Cycle of the Building.**

BIM support generating the 4D BIM which has a lot of features in overtaking the traditional way of scheduling, as it ensures an accurate generation of the quantity take off, doing a full visualization to the building which help the planner to meet the right decision of the predecessors and the successors and assigning the prober buffer between the different trades. Moreover, BIM is used in making the procurement planning, and adding the manufacturing data to the object. BIM also support doing the scheduling for maintenance in the Facility Management phase, moreover BIM support the exchange of the information between architecture, manufacturing, subcontractors which lead by the end a good estimation of the productivity of the project [53].

6. **Supporting The Stakeholders in Meeting the Right Decision.**

As meeting the right decision depend mainly on the amount and quality of information provided to the decision taker, BIM support a data exchange between different disciplinary in the project and also support visualization of the model in order to give the clients a full understanding of the building, and to help them in taking the right decision, by visualizing their idea instead of oral or writing explanation of their ideas. What also was documented about the use of BIM in the industry is the reduction of the amount of the Request of Information (RFI) this reduction is an indication of the success of BIM tool in the communication, and giving a Cristal clear image of the project. Also for the contractor BIM reduce the rework because of the visualization of the model, as the execution team has the option to visualize the model in 3D before going to the site. Skanska was applied

---

[51] (Lee, Park and Won, D 3 City project—Economic impact of BIM-assisted design validation 2012).
[52] (Jones and Bernstein 2012).
[53] (Kymmell 2007)

in its project insulation of a big screen in each floor to provide 3D information to the production team.

3.4.2. Barriers of Implementing BIM

As a matter of fact, any new technology or new techniques have a lot of barriers of implementation from a cultural barrier to some technical barriers, this section will discuss the barriers of implementing BIM in the industry, those barriers can be grouped into six groups which are “lack of a national standard; lack of information shearing across BIM; the high cost of application; the lack of skilled personnel organizational issues; and legal issues” [54]

1. **Lack of National Standard.**

   Construction industry or AEC industry depend mainly on standard and guidelines every country in the world has its own standard or following some type of guidelines to help the industry stakeholder to deliver their product sufficiently with computability of the environment of this country, some building guidelines in different countries have been developed to manage the use of BIM a long with the building standards, but no formal stander was established to generalize and standardize the use of BIM [55].

2. **Lack of information shearing across BIM.**

   Although BIM is a big data shearing and exchange model, it was noticed that a lack of data shearing from some stakeholders and some stakeholders are very conservative in shearing their facts across the model, like some architecture believe that their work is their own and BIM is acting like a hacking tool to their innovational work, and also some subcontractor don’t want to mention the real statues of the progress or the real productivity, all of that factors acting like a barriers towards a compatible model [56].

3. **High cost of application.**

   Implementing BIM in a company require a lot of investment in the IT-infrastructure within this company, as BIM in most cases require a high performance

[54] (Liu, et al. 2015).
[55] (Björk and Laakso 2010).
[56] (Aibinu and Venkatesh 2014).

computer to help in the graphic visualization and doing a proper render and as a higher level of detail of the model and the more data is added to the model the more sophisticated computer is need to process and analysis of this data, also the need of an educated IT-team to support the new software and to develop plug-ins to support more professional data exchange between the other company software. Besides the high initial cost of the software [57]. The implementation of BIM is making a big difficulty for small companies in terms of cost to be implemented, and specially companies with no sophisticated IT-infrastructure [58].

4. **Lack of skilled Personal.**

   Skilled people to operate the BIM model is causing a big barrier towards the implementation of the BIM in the AEC industry. As a company is adopting a new BIM software. It has either one of two options one is educating the current staff how to use the new technology, or going into hiring process and hire a new stuff who are expert in using this technology. The core of BIM is education and training to accelerate the adoption of the new technology, and not only focusing on the teaching of a specific software, but also delivering the idea of big BIM and teaching the core principal of BIM and the culture behind the adoption of this technology. Some studies were carried out on the role of BIM education of the students on the acceleration of the implementation of BIM in the industry and it showed positive relation between the education of the students and the implementation level of the BIM [59].

5. **Organizational Issue.**

   Shifting the company system from the traditional way to the BIM method is really hard task and it cannot be done by dictating some orders from the senior management to do this move. It requires a bottom up approach and collaboration between the stakeholders. It requires to look into the current system and establishing the question how could the implementation of the new technology add value to the current system, and which parts of the current system need to be changed in order to assure a beneficial transformation. This transformation requires modification, and review of the current process and may be developing of new processes in the company,

[57] (Newton and Chileshe 2012).
[58] (Ganah 2014)
[59] (Wu and Issa 2013).

and also changing the view of execution of the work. BIM enhance interoperability which require the whole company to act as a mechanism towards the implementation of BIM [60].

6. **Legal Issue.**

The architecture develops the model and the clients pay for it, hens the clients pay for it then the clients require a complete ownership of data, problem arise when one of the stake holders want to use some data of the model or modifying it at this moment this stakeholder need an authorization to do so [61]. Also one of BIM legal implementation main problem is who is authorized to do what and who is authorized to view what, and who is responsible for this modification, and who is the one who entitled to do the modification, and who carry the risk of modification [62].

BIM implementation barriers is not about one or two of the barriers stated above. But in a lot of cases there is an interaction between different barriers and they are all interrelated to each other as shown in Figure 5, e.g. the Legal issue barrier arise when dealing with one of the stakeholder who is not an internal member of the company like a supplier or subcontractor, then some standardized norms should be existing to manage the communication and the responsibility. Moreover, organizational and work structure issue should be developed to manage this kind of relation. Or for the skilled worker it is related to educational issue which is costing money and standard shortage which lead to lack of skilled profession. What meant of this diagram is that everything is interrelated and there is a need to look at the whole picture.

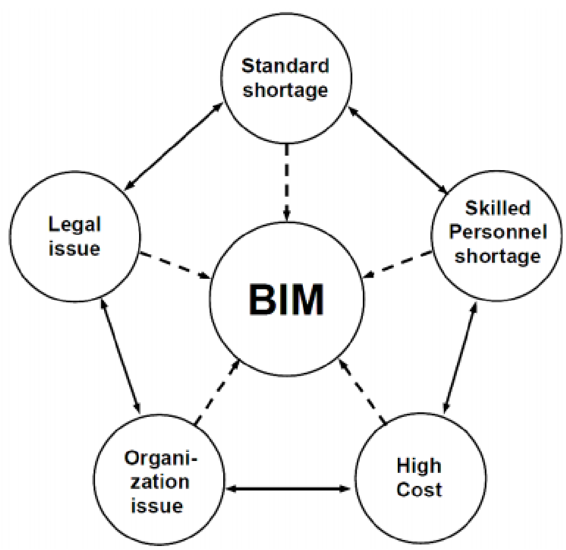


Figure 5 - BIM Barriers

[60] (Arayici, et al. 2011).
[61] (Azhar 2011).
[62] (Thompson and Miner 2006).

4. Lean Principal and Theory

4.1.Lean History Toyota Way

Auto industry is one of the most leading industries as it started in the late of 18th and has experienced a lot of phases and improvement during it's time; improving in different levels (design, tools, process, organization, etc….). Auto industry was and still one of the most competitive markets in the world, which dictate us to take a deep look on this industry from the management prospective.

The story of Auto industry was started by craft industry as it was documented in book (The Machine That Changed The World) [63], which was one of the most cited works in operational management [64]. The characteristics of craft production are:

1. Depend mainly on skilled works who are skilled in more than one discipline, and who also has the hope to run their own business afterword as they had the chance to do it.
2. The Organization is decentralized; main organization which is in direct contract with other workshops to produce most part and much of the vehicle design.
3. Use of very elementary tools to perform drilling, cutting, and machining of the steel. And it was actually small room of improvement in this tools due to the matter of fact that this workshops are small.
4. Low production rate as it was estimated to be 1000 Auto per year.
5. Very big production variation no Auto will be identical even if they follow the same design, as a big error in dimensions was observed.

This model has its success in the beginning and then faced a big failure with after the introduction of the new management technique which was created and adopted by Henry Ford in 1908 and named afterword with Mass Production.

[63] (Womack, Jones and Roos 2007).
[64] (Lewis and Slack, An introduction to general themes and specific issues 2003).

As Henry Ford went on on his new management technique, he wanted to standardize everything in car industry, announcing the birth of centralized industry. The new concept of mass production did not depend on skilled worker rather it depended mainly on low skilled workers but doing only one small job and repeat it over and over. Also for the machines and tools used in the industry the same concept was applied instead of using the machine for doing more than one job and wasting a lot of time and effort in adjusting it after every single job, rather the machine was only used to do one single task without any need for readjustment which saved a lot of time all of that kind of innovation in the management technique lead by the end of average reduction in the task cycle from 514 to 1.19 minutes [65].

What was also noticed in Ford's model is using of the visible hand market concept [66], which mean instead of depending on the free market to supply his company with car parts or material he would rather produce all of it on his own, which lead by the end of the way to an ownership of a lot of iron mining and iron factories, rubber factories. He tried to produce everything himself even the shipping and transportation of the row material the company did it on its own by owning ships, they went also further to own a railway [59]. Some different model in management was developed at this time like Slone's model for General Motors. Nevertheless, it was not a new model or a new management technique it was only some improvement added to the Mass Production system, although this model leaded the industry for more than half century and it was adopted by a lot of European car industry companies, some companies just copied and pasted and other added some slight changes, it was diffused worldwide [59].

Although the great success of the mass production which has lead the industry for almost half a decade, new Japanese companies which was just small craft workshops would like to enter the big world of car industry after the second world war, so they tried to search for the production technology and techniques to enter this industry.

In 1950 a young Japanese engineer Eiji Toyoda, made a trip to the biggest mass production car in the United States where it was famous of the leading car production companies worldwide

[65] (Womack, Jones and Roos 2007) P.32:34.
[66] (Chandler Jr, The visible hand 1993).

at this time Toyota was producing 2685 auto per year comparing with 7000 the Rouge factory was producing every single day [59], this ambitious and intelligent engineer was in his visit to figure out a way to maintain his industry back home and to enter the world competition in car industry, he has documented that the mass production had a lot of flow represented in; a lot of time and material waste. Moreover, his small Japanese company cannot afford all of that massive number of machine and also cannot afford this pig storage space as material or product inventory, he went back home with the welling of establishing new model, which take the benefit of mass production and craft production as well fighting the waste and trying to avoid any disadvantage of both systems [67].

Improvement in the production and process (In-House-Improvement) which contain this main elements:

1. Making small patches and eliminating the large need for inventory, in contrast of the mass production which was famous of this time with a big patch, this new technique helped in reducing or eliminating the need of inventory.
2. Producing only one part before assembling it, which mean produce part by part and avoid having a spare or stock of this part. This technique helped in increasing the quality of the produced part.
3. Giving the right of every one in the production line to stop the production while once any defect was noticed in the assembled part, that helped in increasing the quality and eliminating the rework or repairs required by the end of the production line, in the begging the production line was stopping too often, but after while the production line did not stop at all. In contrast of the mass production companies where the right of stopping the production line was giving only to the production engineer. Nowadays the production line in mass production companies is stopping to more in compare with the companies which adopt lean techniques.
4. Securing the work life of Toyotas employers, by giving them a full life job. In return they should dedicate their effort to develop the production process and adding value to the production.
5. Spreading what is called nowadays anticipating risk culture, which mean every one take part in the production focusing on anticipating the problem and trying to solve it before it takes place.

[67] (Womack, Jones and Roos 2007)

4.2. Stationary Industry in Contrast with Construction Industry

Lean in construction industry is a hot topic right now as some researchers are leading the evolution in this field like (Koskela, Ballard and Howell) those researchers moved some theories from the manufacturing sector and tried to size them to suit into the construction industry which is known with its uncertainty and uniqueness, in order to distinguish the differences between the stationary industry and construction industry, we have to take a deep look on the product itself for the construction industry every single product is a project with a unique environment, unique supply chain, unique design, and unique circumstances. On the other hand, stationary industry, the product is a single of maybe million output of the project, with the same circumstances, supply chain, design, environment with the other products. There is always a room for improvement of the process in both industries but in the stationary industry there is a bigger one due to the fact of the life cycle and the life time of the project, in stationary industry once the project started to produce products then the project is lunched, on the other hand in construction industry once the project produces its product the project is terminated, and enter the documentation phase.

In terms of quality and professional's supervision in stationary industry the project is supported with an experienced team to guide the quality and provide the professional supervision and making a lot of research in that field, so the improvement in stationary industry is not a culture but it is more like a discipline in the company [68]. On the other hand, the quality control in construction is like an office on the site trying to do its best to achieve a reasonable quality, this office is facing the uniqueness of the project, which mean a lot of load on the quality team to develop and continue improving a quality model, and by the end of the day the quality will not be able to be compared with the stationary industry, quality in construction primarily related to product conformance [69].

Supply chain and the order of the activities and tasks, in stationary industry the supply chain is mainly known from the early stage of the project and remain working for the project for long time due to the fact of the big life span of the project and in most cases the project remain for decades and subprojects are developed form this project, also all of this subprojects have or shear

[68] (Ho and Fung 1994).
[69] (Arditi and Gunaydin 1997).

the main circumstances of the old project which mean that the supply chain will remain the same or with slightly changes for longer period. On the other hand, for the construction industry the supply chain is not the same and cannot be managed in the way, due to the unique circumstances of the project and that require a transparent relation between the main contractor and the subcontractor to achieve the project target. For the activities and tasks order in stationary industry the order and the sequence of the work is predefined in the design stage. In contrast, the construction project the tasks and activities in schedule driven form. And this schedule is flexible that a lot of tasks and activities in this schedule could be reassigned and moved to produce the best coherence of the work [70].

Operation domain is totally different between the both industries. On one hand, the operation in stationary industry is well defined from the beginning and rarely to face any changes during the project life cycle also the material used and the labor working in the process everything is well defined which create a secure environment for the labor working and maintain their experience in the process. On the other hand, the uncertainty and change order in construction industry is too much, and reworking is quite often due to the single product of the project which require a lot of rework to produce it. And on the terms of the labor there is no secure job as the labor have to move from a project to other when ended and may be from company to other. Also in terms of wags as in stationary industry it is quite often to have the case that the wags are categorized and a lot of people who are doing the same job taking more or less the same with small variances. But in construction industry the wags are totally different from one to the other even if both are doing the same job, because of the differences in skills and experiences, which lead by the end of the tunnel that construction industry is skilled-based-industry [63].

4.3.Lean Construction

Despite the fact that lean concept was originally produced by Toyota company to serve in the car industry companies in order to reduce the large and enormous size of patches and a lot of machinery used in the process, and trying to focusing on the process itself and how to improve it

[70] (Gao and Low 2014)

and reduce the waste of those processes [71], meanwhile reducing any type of waste during the process and make everyone involved in the manufacturing processing thinking about how to reduce the waste during the process, in other words diffusing of the risk anticipating culture. After lean was adopted in car industry and after its success which was proved by putting one of the small car producer at this time (Toyota) on the map and make it able to compete with the big producer (Ford, GM), and not only compete but also tackle them. Lean was diffused to other sectors in other industries like Healthcare and Construction[72].

4.3.1. Lean Project Delivery System

Ballard (2000a) [73] defined the lean project delivery system and concluded to divide it into 4 main phases: Project Definition (initiation of the project and assigning the project target). Lean Design (do the design from the conceptual formulation to the shop drawings). Lean Supply (getting the design and define and supply the required means to make the projects from the raw material to the prefabricated elements). Lean Assembly (assemble the material and putting it into sequence and manage it with the different resource to add value in the end to the output- this phase is also ended with the close out of the project). In 2008 the same author added new phase to his model which is the Lean Use (include the use and the maintenance of the project which also could be named as FM) according also to the author experience a lot of clients fail to define the purpose of the projects instead they focusing on defining the means of the project [74], which lead to enormous amount of the waste, by defining the purpose of the project that give the AEC (Architecture Engineer and Constructor) the room to enrich the project by their experience to make the project meet the requirements. Moreover, two models were added; production control model and work structure model, and all of that is put into a continues frame which link the end of the project with the beginning of the next one and named post-occupancy evaluation or lean loop to make sure of continuous improvement as show in Figure 6.

[71] (Womack, Jones and Roos 2007).
[72] (Gao and Low 2014).
[73] (G. Ballard 2000).
[74] (G. Ballard, The Lean Project Delivery System: An Update. 2008).

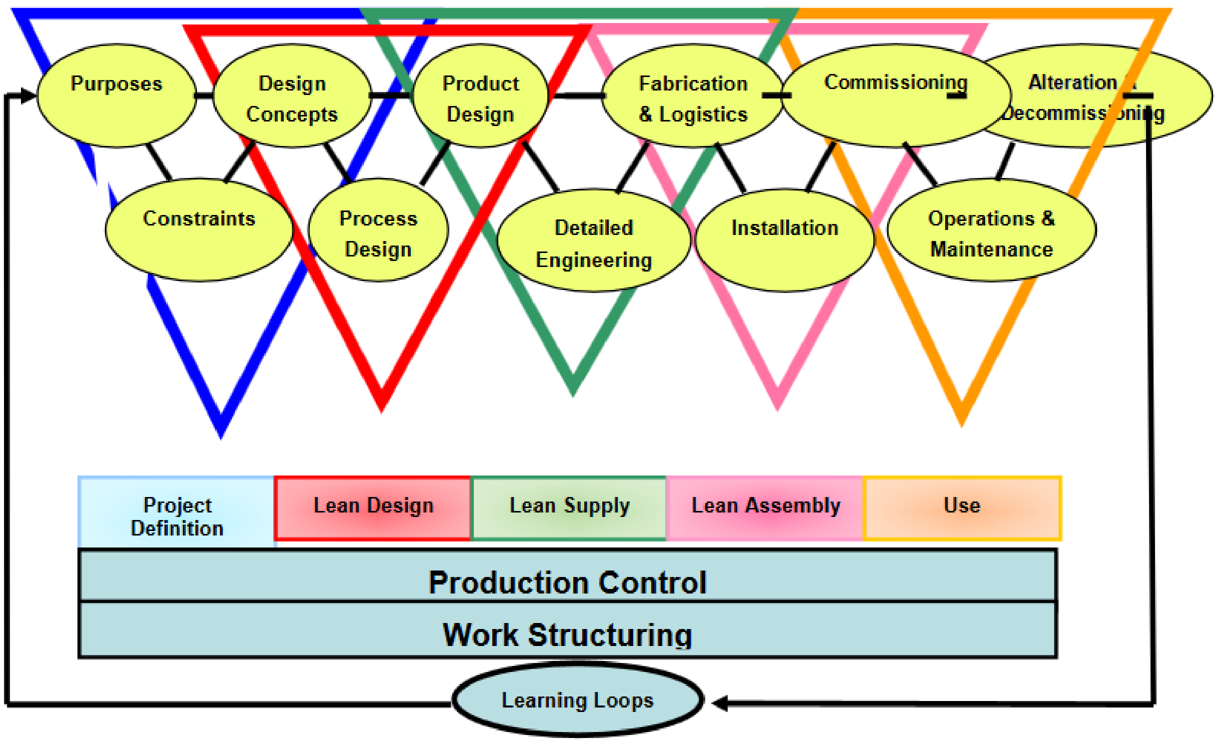


Figure 6 Lean Project delivery System (Ballard, 2000 and 2008)

Lean Project Delivery System (LPDS) is an interaction between the project and the production system and can be defined as a value generation process the stake holder are involved

in the decision in different levels pull theory is used to synchronize the activity, feedback and continues improvement is done during the whole project.

Work Structuring:

This term was orientated by Lean Construction Institute (LCI) to indicate the sequence of the work and to make sure that every resources are put in order to help in the development of the final product which mean everything from material to process are putting into a que to reach the final product. It is the very basic level of the process and is done by dividing the main project into work packages and assign this work package for a specialist group and how to monitor the progress in those group. Besides, how to connect this work package with the next one, and the buffer size between those work package how much? & where? Work structuring is not done once on the project life time but it is done for every phase of the indicated phases and more than one time in every phase [75].

Production control:

The main technique used in Lean Project Delivery System is Last Planner System (LPS) according to (LCI), last planner system is done by dividing the main project into pieces in a hierarchy mood that also will be discussed in the upcoming sections in detail. But production control in the lean culture not about the variance between the actual work and the planned work it is more about removing the abstract for the future work and trying to anticipate the risk related to each work package [69].

Project definition:

This is the early first phase of lean project delivery at this phase the project manager for the client will be the one who carry the responsibility for bridging the communication between the clients and the project stakeholders. In this phase a conceptual design formulation should be done and the design of the production and the processes should also be discussed and having a deep knowledge about the design of the production and process in the next step. Besides, an over view about the processes and production design for the whole project. Also this stage contains the Cost Estimation, Project Duration, and the Target Quality [69].

Lean Design:

At this step the conceptual design which was the output of the prior phase will be the input for this stage, for this stage the decision should be done to meet the client's needs and deliver the maximum value to the customer, also the process design should be done a long side with the product design (while designing the product which is the facility in most cases the process to deliver this product should also be designed. As it was noticed to have a big impact on the reduction of the number of non-value-adding-activities. By the end of this phase design criteria should be developed and agreed by the deign-build team and the client [76].

---

[75] (G. Ballard, The Lean Project Delivery System: An Update. 2008).
[76] (G. Ballard, The Lean Project Delivery System: An Update. 2008).

Lean Supply:

This stage contains a detailed design of the elements which will be used of the delivery of the final product and also go farther for the prefabrication of those elements. And the processes which will be used to assemble them. Also at this stage decision regarding the supply chain and the delivery of the material and the sub product will be taken. Also the size of the inventories at the project, the buffer size between the tasks will be determined. The main purpose of this stage is to have a criteria of the supply chain and link it to the project production [77].

Lean Assembly:

This stage begins with sending the resources to the site and ends with the turning over of the project, at lean assembly phase some guild lines should be taken in order to maximize the value to the client and reduce waste; for material handling it is recommended that the material be touched twice one at the supplier and the second time at the insulation, multi skilled workers should be used, the role of the site supervisors should be changed from giving order into teaching, managing, an coaching the dedicated team, risk anticipation culture should be taken into consideration and should be diffused to every level of the project, feedback and the learned lesson should be the working culture of the project [70].

4.3.2. Push-Pull System

Flow in any industry is based on three techniques Push system or Pull system or a combination of both [78]. Push system can be explained is that the production is oriented based on the predicted demand, that is the definition in production in other words it is Material Requirement Planning (MRP) [79]. In the construction industry the definition of Push system is doing the activities as soon as possible [80] thinking that push system helps in reduction of project risk. However, it was observed according to the same resource that push system does not do any savings on the long run

---

[77] (G. Ballard, The Lean Project Delivery System: An Update. 2008)
[78] (Simchi-Levi, Simchi-Levi and Kaminsky 2003).
[79] (Nahmias and Cheng 2009).
[80] (Simchi-Levi, Simchi-Levi and Kaminsky 2003).

of the project the time saved is waste and the push system require high space of inventory, and increase the opportunity of reworks.

Pull flow is demand driven flow, which mean no product will be produced only if required no forecasting demanding is used. Pull system was noticed to be more beneficial in the production and in construction industry as well because of the short patching size which lead to more control on the output of each patch, also the reduction of the storage area used (as in pull system the whole supply chain is driven in a way to support the pull technique as no material will be imported on site only if a corresponding work is about to start). Although relaying only on pull technique in construction industry was noticed not the best way to manage the project due to the large amount of uncertainty related to the project, and the variability of resources [81] (resource planning for the project is hard to be accurately forecasted because of the short life of the project and some external factors like the weather which could lead to a complete stop of work for days).

A combination of Pull-Push systems is promised to be the best technique in different projects as it was recorded in manufacturing the using of combination of both is the best as the push technique is used in the early stage of managing the supply chain when the quality of information provided is not high and when there is a flexibility in the production, meanwhile when the production starts to go forward to the final output the pull system is deployed (when the supply chain is dealing more with the customer) [82]. To implement that on construction push system can be used in preparing the site document preparing the delivery orders doing some work on site which has to be done any way and the work is not damaged when waited for long time after being finished.

4.3.3. Location Based Planning Process

According to Kenley, Russell, and Olli Seppänen location based planning can be broken down into the following steeps and guild lines83

1. Define the location breakdown structure

[81] (Nahmias and Cheng 2009)
[82] (Simchi-Levi, Simchi-Levi and Kaminsky 2003).
[83] (Kenley and Seppänen 2009). P.203.

2. Define the quantities based on location
3. Build tasks from quantities and define:
    a) Optimal crew
    b) Layered logical links to other tasks
4. Align the schedule and optimize sequence and duration by:
    a) Changing production rates
    b) Changing sequence
    c) Breaking continuity
    d) Splitting
5. Evaluating production system cost and risk (optional)
6. Optimize cost and risk by (optional):
    a) Adding buffers
    b) Changing production rates
    c) Changing sequence
    d) Breaking continuity
    e) Splitting
7. Cost load the schedule
8. Optimize cash flow:
    a) Change payments
    b) Change production rates and start dates
9. Approve the schedule
10. Plan procurement and design schedule:
    a) Use pull scheduling techniques and soft constraints
    b) Do changes to the production schedule only if necessary?

First of all, defining the hierarchy of location break down structure (LBS) this step is half of the battel and the way to break down the project makes big difference in time. As it can save in some cases around 29% without adding any additional resources[84], and according to the same resource a lot of study was carried out on how to define the LBS and the most convenient way to do it is that the LBS should be relevant for the task which is carried out e.g., if LBS needed to be

[84] (Kenley and Seppänen 2009). P.207.

defeined for in-suite concrete work which have to be defined by pour. Or if LBS needed to be defined to the finishing work in the same location it has to be defined by rooms or area, and for facades it can be defined by grid line. But it is highly recommended to make the LBS generalized for all tasks in the project, and according to the same resource in some Finnish case study the design of MEP was changed to help in having better LBS. Second step is defining the quantity based on location, that man assigning every trade quantity per location for this step some recommendations need to be considered; if the quantity will be used to generate procurement plan then the quantity should be divided into two parts material and labor work, and if the quantity will be used just for scheduling porous then less detailed will be accepted, also it must be considered that the same crow could do the same trade in different location, further more if any quantity is unknown its recommend to put a rough estimation to this quantity, that is the usual case when the design is not yet completed [85].

Building task from the quantity; task should be a continues work and uniform and could be done with a specific skilled group. Task should have external dependency not internal. If the task quantity is unknown or not clear; good assumption could be made and reasonable buffer should be maintained. One more important strategy, is using workable backlog task this group is assigned for such activity which does not have mandatory technical successors and can be divided into two areas skilled workable backlog and unskilled workable backlog [86]. And going forward for assigning the crow for each task and simultaneously defining the productivity the productivity has to be based on an accurate calculation and has to be as detailed as possible and when there is a tsk which

Is running very fast and the rate of the task needed to be reduced it will be a fatal mistake to reduce the productivity, instead try to make the task consume more time by adding more quantity to it which could be done by the same crow. After fully defining the tasks and its corresponding quantity next move is defining the relation between tasks relation should be defined in different levels 1st level is defining it per location mean task based location dependency and then defining the location dependency [87]. Afterwards, defining relation in different location for the same task and it is recommended to avoid splitting the task only if it is a must and the whole picture should

[85] (Kenley and Seppänen 2009) P.223
[86] (Kenley and Seppänen 2009) P.217
[87] (Kenley and Seppänen 2009) p.228

be taken into consideration if such action will be obtained, for some activity also it is possible to assign one to one relation when the location is not very important. Then it comes the step of aligning the schedule and there are some tools which could be used: changing production rate by changing the resource, changing production rates by changing scope, changing location sequence of tasks "applying Hoss rule" [88], splitting of tasks, making the task discontinuous when the task is too fast.

Cycle planning this term could be easily find in projects with a lot of repetitive work like in-situ concrete work as this work is more than one activity (form work, rebar, pours) but meanwhile it is repetitive work, then this type of work should be planned in a cycle and this cycle should be planned in early stage in the project because in some cases it could affect the location break down structure of the project [89].

Optimizing risk, risk can be the mean reason of cost and time over run and as it known time over run means cost over run in the forms of overhead costs and plenty costs. And also as it known to all the more we forecast the more wrong we are and the more we detailed in our forecast the more we are detailed in being wrong. That means the future cannot be foreseen. But still there is an opportunity to mitigate risk by reducing the uncertainty within the project. Uncertainty could be defined in several forms; uncertainty in quantity in some cases the detailed quantity or the precise quantity is unknown to the project member and this can be reduced by planning the task according to the current information and the best estimation, and keeping the task updated once the information is available and the most recommended tool for planning the task at this stage is line of balance LOB. By defining the slop of the trade then the productivity is still defined but the quantity is still unknown but also the resource is still unknown and then the planner could manage the resource and the quantity in the way to achieve the target productivity. Uncertainty related to the resource that could be mitigated by hiring more than subcontractor for the same trade but in different location this technique is successful but in big projects, and also daily meeting helps in keeping the management team updated and facing the risk in an early stage.

[88] (Seppänen 2004).
[89] (Kenley and Seppänen 2009). P.231.,

Then it comes the last step of planning and is how to make the plan feasible that could be achieved by making it more realistic in different levels: 1. The quantities should be accurately extracted, the productivity should be accurately calculated. 2. Avoiding of breaking the task which mean in other words discontinuity because it is not realistic that some tasks could start and then

stopped and then start again that will put more costs on this task like the need of maintain the working crow in site for longer time out of work or assigning different work for them which will results of low productivity work besides the need for storing material in site and the needed space to do that all of that costs money. 3. Resource peak highly recommended to be in the middle in the project when this peak at the end of the project that increase the risk of running out of time which lead to running out of money as well. 4. Logic of the relation and calculating the buffer the relation should be realistic and the desired buffer should be maintained. 5. Interface in the same location should be avoided in some cases more resource is added to increase the productivity but that can backfire in some cases.

4.3.1. Last Planner System

Last planner is the system which was generalized by lean construction to be used in monitoring, controlling and work structuring of the project this system was created and improved by Glenn Ballard and Greg Howell in 1980s [90]. Then it was adopted by lean construction institute. Last planner is about increasing the reliability of the production processes and to increase the work flow beside eliminating the non-value adding activities.

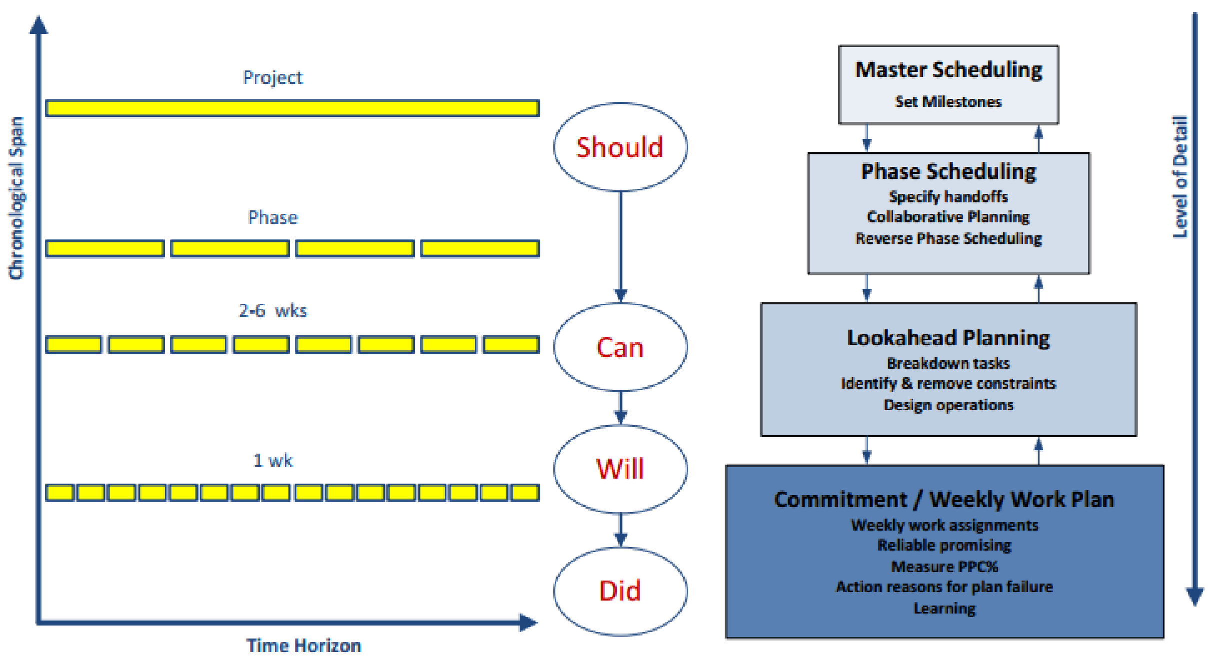
Last Planner manages the relationships, conversations and commitments that together enable program & production planning decisions to be made collaboratively at the lowest possible level in a whole range of one-off production settings — software development, shipbuilding, yacht fit-out, construction and other examples of one-off production. With adaptations, LPS works in new product development and design too [91].

[90] Last Planner is a registered trademark of the Lean Construction Institute www.leanconstruction.org LPS is sometimes referred to as Collaborative Planning, Lean Planning, Workface Planning among other labels. What is offered under these alternative names is not always the full Last Planner System.
[91] (Mossman 2013)

Last planner can be applied to every discipline of the project as safety, productivity, cash flow, delivery of the material and managing of the resources. Last planner is more about collaborative and giving a seat for the project stakeholders to participate in the planning and assuring of the construction processes, as it was explained by the LCI, construction is about promises someone promise you of accomplishment of this stage at this time but you don't need the wrong person to give you the promise. It will be more transparent if the one responsible of the work promise you.

As it is explained in Figure (7) [92], last planner system divides the project into 4 main phases starting with the elementary phase which are:

1. Master Scheduling: Front end planning at this stage the project working team which is high in the hierarchy of the project are involved to produce it and to define the milestones of the project at this phase the question asked is should, the life time of the



master schedule is the whole time of the project.

2. Phase Scheduling: the next level in the project planning at this stage the master plane is divided into smaller parts usually with a length of months and those phases are

Figure 7 - levels in the Last Planner® System (adjusted from Ballard, 2000)

[92] (H. G. Ballard 2000).

assigned to more specialized working groups everyone on those groups is focused on how to deliver value to the customer and the client and how to produce a plane from

which a look ahead plane can be generated, the most used two words at this phase are should and can. And to do this stage in a proper sense the stakeholders or the team member involved at this stage should act in two manners one as a provider and the second as a customer in order to deliver the maximum value to the customer and reduce waste and to make this phase more reliable.

3. Look-ahead Planning: it is the middle chain in the planning of the project which connect the front end planning and the detailed planning, it is the early phase in foreseeing the physical constraints on site and to think how to remove it totally in order to increase the flow of the production process, the main focus of this step is to produce a look-ahead schedule which is aligned with the mile-stones in the master schedule and with high reliability, the output of this phase should be managing the sequences and the rate of the work flow, assigning the resources to the work flow, grouping together the interrelated work, the most common two words at this stage are can and will, and the length of this phase is usually from 2 to 6 weeks [93].
4. Weekly Work Plane: this stage is the front line management and from the characteristics of this stage is which task should be done next week and at which day. The people who are involved in the planning of this stage is the working team itself to make to work more reliable and to predict the problem easily and to have a right promise. As the one who is giving the promise is the same one who will execute it. One of the main outputs of this stage is identifying the make ready action, and synchronizing it to the team promises, the quality of the work should be assisted at this level and the five main question of this stage are:
    - What is the Task?
    - What will be done, e.g., making the form work of the column in the 1st floor.
    - Where it will be done, e.g. defining the exact location of this column on which axes or by coordination.
    - When it will be done?

[93] (H. G. Ballard 2000)

- Who will do it?

The main tool of this stage is weekly work plane, which is a meeting conducted weekly to go throw general concerns for the team, review of the look-ahead plane, review the next week work and discuss the constraints and the obstructs and how to remove it, reviewing the last week PPC and generating the current week PPC, and finally finalizing the next week WWP [94].

In order to achieve the last planner system in practical life some techniques should be used to accomplish it:

- *Pull planning:* it is a technique which was produced by Toyota and diffused to all the industry this technique depends on working backwards from the complication date of the project to the task, it is mainly used in LPS, and the work should be completed only when this work will be released to the other. Pull planning reduce the non-value adding activities and rather focus of the value adding one.

- *Percent Plan Complete (PPC)*: percent plan complete is the monitoring tool which is used in the weekly work plan. It is a gauge divide the work done by the work planned (did/will). And used as an indicator to measure the work performance of this week.

- *Reason of Variance & Learned lesson:* after completing the PPC the reason of variance if it is existing should be checked and added to the learned lesson list. One important technique also while doing the planning of any upcoming task the learned lesson should be reviewed.

- *Reduction of No-Value-Adding Activities:* non-value-adding work is the waste and it was stated that there are mainly seven sources of waste: 1. Transportation: keep moving of the material of the same shape from a place to other without adding any value for this material. 2. Inventory: by production of something which will not be used and has to be stored for long time, or ordering some material which will not be used and need

[94] (Kalsaas 2012).

to be stored. 3. Motion: keep moving of human and machine without adding any value to the final product. 4. Waiting: that indicate the work is sopped and no longer work available to do mean while the final product is not delivered. 5. Over Processing: this is done by doing work which is not required or providing a quality which is not required by the customer or the client. 6. Over Production: doing much work before its releasing time, that is also against pull technique. 7. Defect: producing un prober parts with a lot of flow, those parts will not be used any way and it is more or less waste of time and resources [95].

- *Make ready*: is a term used to define a set work of actions which is set to be ready to be used for the work plan, only the work which is included in the weekly work plane is made a make ready list for it, make ready is about foreseeing the risk and managing a set of actions to deal with it, in make ready plane the T-shape (whole team work together) is formed to set the action.

- *Daily Huddle Meetings:* the main purpose of daily huddle meeting is to enhance the communication and giving an update every 24 hours to avoid any accumulation of problems, topic which should be discussed are as what is the task to be done today and who will do it, and is there anything blocking the work. The meeting is not to discuss any technical problems, and it is recommended to not take more than 15 minutes [96].

By the end the tools which is used to implement the Last Planner System are very simple the required tools are sticky note, white board, Microsoft office, a management software like primavera or Microsoft project, and a meeting room and it is really important not to deviate the focus of the system away from its target and keep focusing on the fancy tools to be used.

[95] (Gunasekaran, Patel and Tirtiroglu 2001).
[96] (Poksinska, Swartling and Drotz 2013).

Benefits and implementing challenges of Last Planner System:

Fernandez-Solis, Jose L., et al. 2012, conducted a survey on last planner system and the corresponding benefits of it on 26 case study and the results can be listed on Table (1 & 2) [97].

Benefit of last planner system	**No. of the case studies**
Increase work flow reliability	9
Reduced project delivery or production time	5
Improved supply chain integration	3
Improved communication among project participants	3
Less firefighting or fewer day-to-day problems	3
Improvement in quality of work practice at construction site	2
Enhancement of managerial practices in construction projects	2
Knowledge expansion and learning among project teams	2
Reduced stress levels on construction sites	2

Table 1 - benefits of using LPS (source: Solis et al 2012).

An according to the same resource the challenges could be listed in Tabel 2 with the courrsponding number of case studies.

Challenges of implementing LPS	**No. of the case studies**
Organizational inertia or resistance to change or "This is how I've always done it" attitude	16
Lack of commitment to LPS implementation or negative attitude towards new systems	12
Lack of human capital: lack of understanding of new system, difficulty in making quality assignments, or lack of skills, training, and experience	13
Lack of leadership or failure of management commitment or non-supportive organizational climate	7
Lack of stakeholder support	5
Lack of empowerment of field management or lengthy approval procedure from client and top management	5
Poor use of information generated during implementation of LPS	4
Partial or late implementation of LPS	3

Table 2 - Challenges of implementing LPS (source: Solis et al 2012)

[97] (Fernandez-Solis, et al. 2012).

5. Analysis of Case Studies

5.1.Introduction

In this chapter, the first research question; How BIM and Lean impact the Project (Product, process, Organization)? And the second research question; Who from the stakeholders benefit from BIM and Lean? Will be answered based on the review which was conducted on the literature in field of BIM and Lean-Construction. Besides, the analysis of 24 different case studies in field of BIM and Lean-Construction. As a matter of fact, results and impacts which were recorded in one project cannot be generalized [98]. Towards providing reliable results this chapter will investigate 24 different case studies from different countries with different companies.

5.2. Development and Limitations of the Analysis Framework

The frame work is developed based on 24 cases, which were chosen depending on the successful implementation of BIM and Lean-construction tools. During this study main focus was laid on having different cases form different countries, different companies (as the culture is playing a critical role when it comes to management and anything which is related to people behavior).

This study is based on two assumptions; 1. The implementation of BIM and Lean-Construction tools is different from one project to another depending on the project and company characteristics. 2. The implementation of BIM and Lean-Construction will have an affection on the project or the company on three levels (the process of doing the business, the organizational frame of the project or the company, the final product [99]).

The framework was developed to be as objective as possible (the results which was recorded was more about the impact which was recorded and is not based on the author opinion of

[98] (Yin 1994).
[99] (Gao and Fischer 2008).

the case study and not on the opinion of any engineer or architect who was involved in the case study.

The results of the case studies analysis were assured to be consistent (could be applied in different projects, and not a one project case; By the repeating of the same results in more than one different project) the results are recorded only when it has appeared in more than one different case otherwise not recorded and considered as an outlier or further researches are required on this results to investigate it more in different projects.

During the selection of the case studies it was assured that, the implementation of BIM or Lean-Construction will add value to the project (not for commercial use of the tools). Otherwise the case study was skipped.

5.3. Overview on Case-Studies and the Approach of Data Collection and Analysis

This study is based on the analysis of 24 different cases as mentioned above, first the case study name was mentioned with the resource (for some cases different resources are used to provide more reliability to the results and to draw a bigger picture to the project). The project type was mentioned as well and the location of the case study was mentioned, as indicated in *Table 3*.

The cases are from different countries and with different company (most of cases are observed in Finland and U.S.A due to the high level of development in BIM and Lean-Construction in both countries, but also some cases are conducted in Peru, Saudi Arabia, and China).

The 24 case studies which were selected covers the whole life cycle of the project from the feasibility study to the operational phase (but more attentions were paid in this thesis to the impact on the development phase of the project more than the operational phase of the project). Nevertheless, the operation phase was mentioned to indicate the use of BIM and Lean but not detailed). Moreover, *Table 4* spot the light on the case study implementation phase. Also a short description was provided for every case in *Table 5.*

Most of the case studies in this chapter BIM is used in parallel with the using of Lean-Construction, which lead to a conclusion of “BIM is the technology which will be used to accomplish the project target (reduce the waste and add value to the final product) and lean is the environment which needed to get the benefits of the using of this technology otherwise the technology alone will not help”. In other words, when a plant is seeded it needs a specific environment to grow up (water, sun, fresh air….) otherwise the plant will die and we seed the plant to get use of its product (fruit, view, reduction in global worming…….), it is the same the BIM is the plant and Lean is the environment, and the project is the final product which we are pursuing. All of the case studies which have been selected were originally implemented to demonstrate the use of BIM and Lean.

After the cases are selected they are analyzed according to the frame which was discussed before, and evaluated depending on the impact on the project, the impact on the project is characterized according to the literature review which was conducted earlier in this thesis, which lead to a conclusion of; the project could be broken down into three main areas (process, organization, product). Also the parties who will get the benefit form the implementation are listed depending on the impact type.

By the end of every analysis table data aggregation and clustering will be done in chart format and then the results will be discussed afterword in order to develop a road map for the using of BIM and Lean-Construction.

Table 3 - Case study ID, Name, Type, Location

#	Project	Project Type	Location
1	Courtyard by Marriott [100, 101]	Renovation of office Building into hotel	Portland, Oregon, U.S.A
2	Sutter Medical Center [102, 103]	Demolishing of an existing medical building and construction of new one	Castro Valley, California, U.S.A
3	Maryland General Hospital [104, 105]	Extension of existing Building	Baltimore, Maryland, U.S.A
4	St Joseph's Northeast Tower addition [106]	An extension of existing hospital	Eureka, California, U.S.A
5	St. Olaf College Field House [107]	Developing of Field House for the college	Northfield, Minnesota, U.S.A
6	Cathedral Hill Hospital [108]	Developing of new hospital	San Francisco, California, U.S.A
7	Fairfield Medical Office Building [109]	Design and construction of new building in the hospital	San Francisco, California, U.S.A
8	Retreat at Fort Baker [110]	Rehabilitation of existing 23 building, and construction of 14 building with the landscaping area	Fort Baker, Sausalito, California, U.S.A
9	UCSF's Cardiovascular Research Center [3]	Construction of new building	San Francisco, California, U.S.A
10	The Nasif Historical House [111]	Renovation and rehabilitation of a heritage building	Jeddah, S.A
11	construction of a Leaching Pad [112]	Construction of leaching pad and 7.1 km of highway.	Peru

[100] (Boggs 2010).
[101] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011).P.415-430.
[102] (Aliaari and Najarian 2013).
[103] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011).P.431-479.
[104] (Pikas, et al. 2011).
[105] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011)P.480-493.
[106] (Kenley and Seppänen 2009). P.509-518
[107] (Ballard and Reiser, The St. Olaf College Fieldhouse project: a case study in designing to target cost 2006).
[108] (F. R. Hamzeh 2009), p.69.
[109] (F. R. Hamzeh 2009), P. 81.
[110] (Hamzeh, Ballard and Tommelein 2012).
[111] (Baik 2017).
[112] (Olano, Alarcón and Rázuri 2009).

#	Project	Project Type	Location
12	Crusell Bridge [113] [114]	Construction of cable stayed bridge.	Helsinki, Finland
13	Kamppi Center [115] [116]	Building of complex	Helsinki, Finland
14	Varma Salmisaari Project in Helsinki [117] [118]	Development of 12 story office building	Helsinki, Finland
15	Four story office building [119]	Design and construction of four story office building	Helsinki, Finland
16	Camino Medical Center [120]	Developing of medical center	Mountain View, California, U.S.A
17	100 11th Avenue [121]	Design and analysis of complex building	New York City, U.S.A
18	MIT Ray and Maria Stata Center, Boston [122]	Development of institutional facility	Cambridge, Massachusetts, U.S.A
19	One Island East [123]	Develop of complex project	Hong Kong, China
20	Helsinki Music Center [124] [125]	Develop of a music center	Helsinki, Finland
21	Hillwood Commercial Project [126]	Conceptual development of a project	Dallas, Texas, U.S.A
22	United Sate Coast Gard [127]	Using of BIM to manage Portfolio facilities	U.S.A
23	Skanssi Retail Center [128]	Developing of retail center	Turku, Finland
24	Aviva Stadium [129, 130]	Develop of new stadium shell	Dublin, Ireland

[113] (O'Keeffe 2014).
[114] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011), P.494-513.
[115] (Kenley and Seppänen 2009) P.519.
[116] (Vico Case study 2014)
[117] (Vierula and others 2015).
[118] (Palmberg 5D BIM Case Study 2015).
[119] (Lu, Won and Cheng 2016).
[120] (Khanzode, Fischer and Reed 2008).
[121] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011, 514) P. 514.
[122] (Hastings, et al. 2006).
[123] (Riese 2008).
[124] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011, 539). P. 539
[125] (Jiang and Lei 2017, 3-9).
[126] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) P.557
[127] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011) P.566
[128] (Kenley and Seppänen 2009) P. 529
[129] (Hines 2013).
[130] (Eastman, Eastman, et al., BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors 2011). P. 397

Table 4 – Case study Phase

Case #	Feasibility	Concept Development	Design Development	Design Document	Pre-Construction	Construction	Operation
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							

Table 5 - Case ID, and Description

#	Narrative
1	Using of BIM and a corresponding leaser scanning Technology to do the remodeling of the existing building and do modeling of new three floors which is attached to the building, besides the modeling of demolishing of the existing facades and replacing it with new one. One of the main objectives of this project is to meet the LEED Certificate.
2	Using of BIM in an integrated project delivery (IPD) project, during the demolishing phase of an existing facility and replacing it with new one. And using of BIM in the frame work of lean tools. Using of BIM in getting the Permits from the (Office of Statewide Health Planning and Development). The IPD contract involved 11 members who work together using the BIM platform.
3	The BIM in this project was suggested by the project manager of the construction company when he figure out that BIM would facilitate the clash detection faster and would be better for the using of close out of the project. The project is an extension of an existing Hospital and equipping it. The model was further used to support the mobile technology, besides being used for the operation phase, facility management and documentation.
4	This project is an extension of existing building, 3D BIM technology was used, the schedule is done in two methods first in CPM for contractual purpose and the second was done in LBMS with integration with the 3D model in order to develop the 4D model.
5	A lean construction approach (Target value design) was used to develop the field house of the collage. The contractor has a big experience in lean construction tools and the target of the project is to deliver the project under budget within a shorter timeframe comparing with similar projects. By the end of the project the project is done in .58 of the time consumed by similar project and within a reduction of 35% in the project cost
6	Developing of 555-bed hospital with a budget within 1.7 billion $, this project is very unique one as this project implement LPS technique as long with using BIM technology, also using of the target value design, and the delivery system of the project is IPD. The project also has exposed teaching people of the use of new technology like BIM.

#	Narrative
7	Designing and construction of new office building for a medical center the project is done within budget of 19.6 million $ and within timeframe of 25 months. The project was delivered under IPD method, BIM technology was also used, lean construction tools for collaboration (LPS), and target value design were also adopted by the project.
8	This project is consisted of three different projects (rehabilitation, new construction, landscaping areas). The project was done by participation of more than one company under IPD type of contract. Lean construction tools like (LPS, and Pull technique is adopted by the project). BIM model is developed to manage the construction stage.
9	This project is construction of five story building for research in the university of California the total area of the building is 232,000 square foot. The project is delivered with Design-Bed-Built contract, meanwhile the client and contractor were seeking more collaboration using lean construction tools.
10	This project is kind of unique one to this list as this project is about using of BIM technology in a heritage building, the corresponding technology which was used in the building was laser scanning and photogrammetry techniques, the model was done to develop a 3D drawings of the building from a laser scanner.
11	This project is developed in extremely hot weather in Peru the project is contained construction of a Leach Pad with an approximate area of 324380 m^2 and with a budget of $ 20 million, the project also contains construction of pipe line and a High way with total length of 7.1km and a budget of $7milion, the construction time of the project is calculated to be 60 weeks. The management and control methods in the project was developed in such a way to consider the theories which is developed by the PMI and the LCI.
12	Construction of cable stayed bridge with a total length of 143.5m and traffic width of 24.8m. the project started on fall of 2008 and ended in the late of 2010. During the design and construction of the bridge the project teams developed BIM model and they were using lean construction tools. The bridge was designed WSP Finland and constructed by Skanska Civil (both companies has a great experience with BIM and lean Construction.

#	Narrative
13	Kamppi Center is one of the remarked buildings in Helsinki the construction of the complex was started in 2002 and completed in 2005, the SRV group was able to deliver it 6 months ahead of the schedule the total project budget is 500 million Euro, the complex consists of six story shopping building, office areas, living area, central bus station, terminal of metro, and parking space. The project was constructed with 800 subcontractors and up to 2000 labor onsite nevertheless the project management was able to manage this huge numbers. The technology which was used in this project was cutting-edge technology of this time as they managed to use 3D model and used Vico control, besides the use of the LBMS.
14	Varma Samisaari is an office complex which is developing in Helsinki, Finland this office complex consists of 8 office buildings with a central courtyard the project is with total area of 66000 sq. meter the buildings are with up to 12 floor heights and two underground parking area the BIM models in this project was developed till the use of 5D model in controlling the construction process.
15	Construction of 4 floor office building in Helsinki, the construction is done of concrete and wood the project total duration is with total 351 days (240 working day), the project was done using a 5D BIM, the model was developed from the design stage to analysis the different design alternatives and to do cost beneficial analysis, then the use of the model was extended to the control of the construction stage and to make the communication and reporting, the computer developer have developed an add in to connect the BIM software (Naviswork 2014) with excel. The project is done with budget of 3125661$.
16	Camino medical center was developed in California with a project of total budget of U.S$100 million, the total area of the project is 22,500 sq. meter, the project was developed using a 3D model in the beginning to study the different possibility of the design, also the LBMS was used in the project.
17	This case study is about 21 story building, the case study toke place at the design phase tell preconstruction, the case study demonstrates the use of BIM in the managing of the design process, and facilitating the communication and collaboration between the design team member, besides the normal use of BIM in visualization of the design.

#	Narrative
18	The development of institutional facility, the project duration was 4 years, project delivery method is Construction Manager at risk, the project was done using the 4D BIM and lean construction tools was used to increase the collaboration and to do better cost value analysis to the project, the floor area of the project is 67000 sq. meter.
19	One Island East is a project in Hong Kong, China. The project is 70 floors building with 2 basements the project budget is U. S$300 million and the duration of the project is 24 months. The BIM is implemented in the project due to the desire of the client to integrate BIM form the design stage to the construction and the client is looking the BIM model to be used for the Facility Management. The BIM model is used in clash detection site planning, and the 4 D model was used. Also some innovative methods was used to integrate Microsoft Project with the BIM models
20	Helsinki Music Center, is a music center constructed in Finland the building total floor area is 36,000 sq. meters the building main concert hall could accommodate up to 1700 audience, the owner of the building is the city of Helsinki. BIM model was developed form the design stage to the construction and site planning also the model was used in doing energy analysis, and for Facility management as well. The BIM model is an integration of different models for 3D visualization, clash detection, schedule, and cost estimation. Some innovative solution from the IT was developed and a lots of plug-ins was developed to facilitate the communication in between.
21	Hillwood Commercial Project, the case study demonstrates the use of BIM in developing the concept of the building and exploring different design option, also the different options were designed with the integration of costs, the model helped the client to get to know his ideas better.
22	This case study demonstrates the use of BIM at strategic level and making tactical decision regarding the building and doing feasible cost analysis. The use of BIM for United Sate Coast Gard is used to manage around 8,000 owned or leased buildings, and land holding.

#	Narrative
23	The case study of a retail center in Finland with a total area of 128,000 sq. meter which accommodate 96 ranging from small to medium retailers, the project also has a total parking space of 2,400 cars and the project duration starts on January 2007 and ends in April 2009. The BIM was developed for the design purpose and then was deployed for clash detection and doing the scheduling after words it is extended till the construction phase and managing the communication and collaboration in the project. Also LBMS was used.
24	The case study demonstrates the use of BIM in developing of Aviva Stadium the project budget is 410 million Euro, the project is done mainly with standardized and prefabricated elements. The BIM was deployed from the design phase and also some innovative solution to link the structure model to the BIM was developed, the BIM also was used during the construction phase as well.

Legends	
G.C	General Contractor or the Main Contractor of the Projects
T.Cs	Trade Contractors or the sub-Contractors
Suppliers	The party which provide supply of the material or some services
Client	This term represent the owner weather it is a single party or a joint venture
Designer	The party which is responsible for providing the design (regardless to the discipline)

5.4. Analysis of BIM Impacts

In this section the impact of BIM will be analyzed in tabular form (*Table 6*) on the project (Product, Process, and Organization). Group clustering of the use of the model was done, and the corresponding impact of the model on the three levels which are stated above was recorded with the corresponding cases which are listed below of each impact. There is also one cell at the end which state benefit to whom in order to know who is the stakeholders party get the benefit (it is not a must that the stakeholder who will use the model to have the benefit, but what was recorded is in some cases one party of the model users will get the benefit, and in some cases all the users will get benefits, and in some cases other party who did not use the model still shear some benefits of the model besides other stakeholders).

Table 6 - BIM Imapct Benefit Analysis

Use of the model	**Impact on the Project (Product, Process, Organization)** • Product: the impact of the design and the building Quality • Process: impact on managing the sequence and work flow • Organization: impact on engaging the stakeholders in the project		**Who get benefits**
1. Documenting of as built drawings	Product	The quality of drawings are better and create a visualize documentation which can rely on it in exploring options for operation phase	Designer Client
		Case # 1, 3, 10, 12, 19, 20	
	Process	Facilitate the integration of new technology such as leaser scanning in producing the as built document, facilitate the data manipulations .	Designer G.C
		Case # 1, 3, 10, 12, 19, 20	
	Organization	Integrate more than one designer team and the client in taking the decision, and facilitating the using of more than one crow to do the as built and manipulating the data in the end on one model	Designer Client G.C T.Cs
		Case # 1, 3, 10, 12, 19, 20	

	Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
2.	Facilitate the usage of new Technology (e.g. lesser scanning, 3D printing)	Product	Providing a clear drawings, and increasing the quality of the drawings by increasing the reliability	Designer
			Case # 1, 3, 10, 12	
		Process	Facilitate the data transfer between different plat forms, The option of editing the drawing in case of any error occurred	Designer G.C
			Case # 1, 3, 10, 12	
			Laser scanning was used to make a documentation, reporting of the current situation, and for Quality assurance during the construction	G.C
			Case # 12	
		Organization	Acting as a platform to facilitate the communication between the team, and integrate downstream management in decision making	Designer Client G.C
			Case # 1, 3, 10, 12	
3.	Achieving of some sort of certificates like LEED, BREEM	Product	Facilitate the target Certificate achievement (by exploring, checking, and analyzing the feasibility of different options towards the certificate achievement).	Designer Client
			Case # 1, 2	
		Process	Improve the design process by exploring different options and making a fast and reliable analysis of the design (e.g. energy analysis model, lighting of the building, checking the insulations option and evaluating them during the design)	Designer
			Case # 1, 2	
		Organization	Bridge the communication between the design team and the certificate experts, improve the collaboration between the team member, involve the Client for some decision making.	Design Client
			Case # 1, 2	
4.	Exploring and analysis of different design options	Products	High quality design which fulfill the requirements of the client and reliable to construct.	Design Client G.C
			Case # 1, 2, 4, 6, 7, 8, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24	
		Process	Provide the option of doing different analysis of the design in order to choose one, managing the date between the different	Design G.C

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	design parties (e.g. Structure analysis and the Architectures). Acting like a data base to reflect the current building situation for the renovation purpose.	Design G.C
		Case # 1, 2, 4, 6, 7, 8, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24	
		The model was used to do comprehensive analysis of the energy consumption and also was used afterwards to monitor it.	client
		Case # 20	
	Organization	Involving experts in decision making, and involving the client. Facilitate the data exchange between different parties in the project	Designer GC Client
		Case # 1, 2, 4, 6, 7, 8, 10, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24	
5. Cost-Benefit Analysis	Product	Achieving the best Cost-Benefit Scenario by exploring more options and reducing the time to explore it	Client Designer
		Case # 1, 2, 4, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21, 22	
	Process	Increase the reliability by reflecting and linking the cost to the quantity take off, and making the quantity take off more accurate, increasing the speed in the checking of different scenarios. provide the comparison between different scenarios.	Client Designer
		Case # 1, 2, 4, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21, 22	
	Organization	Increasing the communication between the client and the designer team. Involve more parties to serve the success of the project. Involve the GC in some decision regarding the costs of such items or construction technique.	Designer Client GC
		Case # 1, 2, 4, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21, 22	
6. Document control	Product	Provide organized and clear document data base	G.C T.Cs Designer
		Case # 1, 2, 3, 6, 7, 14, 15, 17, 19, 20, 22	
	Process	Filling and accessing of the project Documents (emails, Presentations, models, and the like) all in one data base and also linking the relevant information to the	G.C T.Cs Designer Client

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	relevant object. Providing documenting and sorting of information	
		Case # 1, 2, 3, 6, 7, 14, 15, 17, 19, 20, 22	
	Organization	Facilitate and bridge the communication between the project stake holders	G.C T.Cs Designer
		Case # 1, 2, 3, 6, 7, 14, 15, 17, 19, 20, 22	
7. Explicitly define the owner goal	Product	Using of BIM to help the owner to make his choices clear and to formulate an overview about his needs, by visualization of different scenarios and the corresponding costs to these scenarios. Making a clear project goal by explicitly stating it in project documents.	Owner Designer G.C
		Case # 1, 2, 4, 6, 7, 8, 14, 15, 16, 18, 19, 20, 21, 22	
		The client is able to understand more about the function of the facility and how it will work.	
		Case # 1, 2, 4, 6, 7, 8	
8. Construction Permit Approval	Product	The permit was issued faster (as the drawing and details required to the permit was done faster)	Client Designer
		Case #. 2	
	Process	Design process drawings are done faster and with collaboration and more reliable which lead at the end issuing the permit from the first submission. Visualization of the model made it easier for the design team to distinguish the error very fast.	Designer
		Case #. 2	
	Organization	The MEP, Structure engineer, and the Architect, are aligned together in order to generate the permit design drawings.	Designer
		Case #. 2	
9. Visualization of the schedule / adopting 4D BIM	Product	Reduce the uncertainty related to the project Reduction of time and cost overrun. Generate a schedule which facilitate the communication. Reduce the time in understanding reporting and notes related to schedule. Increase the schedule reliability by increasing the visualization checking on it.	Client Designer G.C T.Cs
		Case #. 2, 3, 4, 6, 7, 8, 12, 14, 15, 18, 19, 20, 24	

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	Instead of hanging sticky notes on the wall, the notes and the information regarding the schedule is linked directly to the element on the BIM platform. The lesson learned, and the current situation was linked to the objects. Enhance and make more parties to add value into the schedule by shearing it very easy. Everyone has his/her own authorization to use the model (view, edit, feedback, mail, adding notes). Facilitate the communication between the project engineer regarding the sequence of work.	Client Designer G.C T.Cs
		Case #. 2, 3, 4, 6, 7, 8, 12, 14, 15, 18, 19, 20, 24	
		The 4D model was integrated with last planner system. Lots of improvement was noticed after this integration.	
		Case #. 6, 12	
	Organization	Engage more project participant in the planning. Allow the top management of perusing the construction process very easy. Create collaboration between Front line management and the Front End Management. Client is informed with the day to day current situation.	Client Designer G.C T.Cs
		Case #. 2, 3, 4, 6, 7, 8, 12, 14, 15, 18, 19, 20, 24	
10. Remote coordination between the project stakeholders (virtual big-room)	Product	Eliminate the cost needed for the Big Room (meeting room which all the project stakeholders are meet in) Organize the flow of information during the meeting.	Client Designer G.C T.Cs
		Case #. 2, 22	
	Process	The process is more organized and the flow of the information is more organized. A big room for exploring different areas than before. The meeting process did not consume that much time as used.	Client Designer G.C T.Cs Suppliers

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	Big opportunity for the relatedness side discussion.	
		Case #. 2, 22	
	Organization	The virtual big room concept is done by breaking down the physical big room into small meeting rooms every cross discipline is meet in and using a sheared virtual model to manage the meeting, one remote room is responsible for the coordination between the different rooms.	Client Designer G.C T.Cs Suppliers
		Case #. 2, 22	
11. Federated Document collaboration system	Product	The accessibility of the model form different places worldwide. The project is better aligned to its targets (by providing consultation faster and doing reviewing and revision faster	Client Designer G. C T.Cs Suppliers
		Case #. 2, 22	
	Process	All the project document is sheared on one big server; the system is designed in such a way to automatic upload the document once done. Providing a last updated version of document to all the project participants. Everyone is authorized with a limiting access depending on his/her role in the project. Automatically notify the users when there is a change on the model. Reduce the uncertainty related to the project, and reduce of miss flow of information.	Client Designer G. C T.Cs Suppliers
		Case #. 2, 22	
	Organization	Every discipline develops the relevant model or document and every model or document are sheared on an integrated server. Facilitate the collaboration.	Client Designer G. C T.Cs Suppliers
		Case #. 2, 22	
12. Supporting of the design of the prefabricated elements	Product	The dimensions and the specification of the prefabricated elements is more precise and accurate.	Designer G. C Suppliers T.CS
		Case Studies No. 2, 4, 6, 12, 17, 18, 19, 20 24	

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	The design is developed in 3D environment which represents a real simulation to the reality	Designer G. C Suppliers T.CS
		Case Studies No. 2, 4, 6, 12, 17, 18, 19, 20 24	
	Organization	Make the construction process more fast and simple. Reduce the need for onsite labors, storage areas, and manufacture areas	Designer G. C Suppliers T.CS
		Case Studies No. 2, 4, 6, 12, 17, 18, 19, 20 24	
13. Model based cost estimating.	Product	Facilitating the estimating process. Providing and viewing of the other alternatives faster and more accurate. The estimating process could be done after any changes faster, and more often than the traditional method.	Client Designer G.C
		Case Studies No. 2, 3, 14, 15, 19, 20	
	Process	More than one software is used (one software for the 3D model and other one for estimating) for some BIM software it has its compatible cost estimation. Not everything could be done automatically (e.g. construction joint needed to be done manually). In the beginning of the estimation process the there is a big room for errors (people are still not familiar with the software and the process)	Client Designer G.C
		Case Studies No. 2, 3, 14, 15, 19, 20	
	Organization	Collaboration between the model participants is required to process the cost estimating model. Some software requires plug-ins to connect them to the estimating model. Education for the estimating team to be familiar with the software.	Client Designer G.C
		Case Studies No. 2, 3, 14, 15, 19, 20	
14. Model based Facility management	Product	Better visualization of FM process. Reduce the respond time for maintenance. All the data on one platform.	Client
		Case Studies No. 3, 19, 20	
	Process	Integration of the 3D model and the MEP, as long with the data captured in site for the	Client

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	construction process, besides the data for the equipment. The using of Computerized Maintenance Management System (CMMS) is used to schedule the maintenance and monitoring and controlling the process. Physical equipment are coded on the model	
		Case Studies No. 3, 19, 20	
	Organization	Engineers, Managers, inspectors, and maintenance personal have access to the same database.	Client
		Case Studies No. 3, 19, 20	
15. Site utilization and planning	Product	Better space planning and getting more benefit from the site area. Making better analysis for the moving machinery in site e.g. tower crane orientation and rotation angle design.	G.C T.C
		Case Studies No. 2, 3, 14, 15, 19, 20, 24	
	Process	Simulation of the future situations could be done. Managing of the transportation onsite is done in better sense with less conflict. Linking the site management with the schedule and quantities is done way easier, and that helped in reduction of the storage area and developing of better logistic plan.	G.C T.C
		Case Studies No. 2, 3, 14, 15, 19, 20, 24	
	Organization	Logistic department of the project are able to do their job better than before, the ability to shear experiences in site planning form different sites.	G.C T.C
		Case Studies No. 2, 3, 14, 15, 19, 20, 24	
16. Enhance communication and collaboration.	Process	BIM is used to integrate more members in the project decision during the design and construct, also it was used to facilitate the communicating between the project team and the client. It was recorded in the case studies the use of BIM in communication reduce the room for error and also help in having better design option which add value to the project (there is no right design and wrong design there is better design and pad design and BIM facilitate having the better design).	Client Designer G.C T.Cs Suppliers

Use of the model	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued		Case Studies No. 1, 2, 6, 7, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24	
		The use of BIM during the construction to facilitate the communication and collaboration between the project stake holders lead to a reduction in project time and cost and a permeant accessibility to the project documents. Also reduction in the number of RFIs and in some cases total elimination of RFIs	Client Designer G.C T.Cs Suppliers
		Case Studies No. 1, 2, 6, 7, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24	
17. Contract proposal / close the contract	Process	Make a brief model of quantities which lead to a precis estimation of the bed and getting to win the contract. The construction sequence and site planning is done easier in early stage of the project and everything is merely going as the planned. The client get the benefit of lower cost high value model.	G.C Client
		Case Studies No. 18, 22	
	Organization	The contractor is able to win the contract by showing the client his ability of work on the model which increases the reliability and trust between the client and the contractor. The client wants to maintain the same contractor for future work (the construction work was done within the planned cost, schedule, and budget)	G.C Client
		Case Studies No. 18, 22	

5.5.Findings of the BIM Impacts Analysis

As a result of the analysis of the twenty-four case studies the BIM in approach in construction industry benefit could be clustered into seventeen group and they could be listed as follow sorting by the frequency of the cases which are recorded on each one;

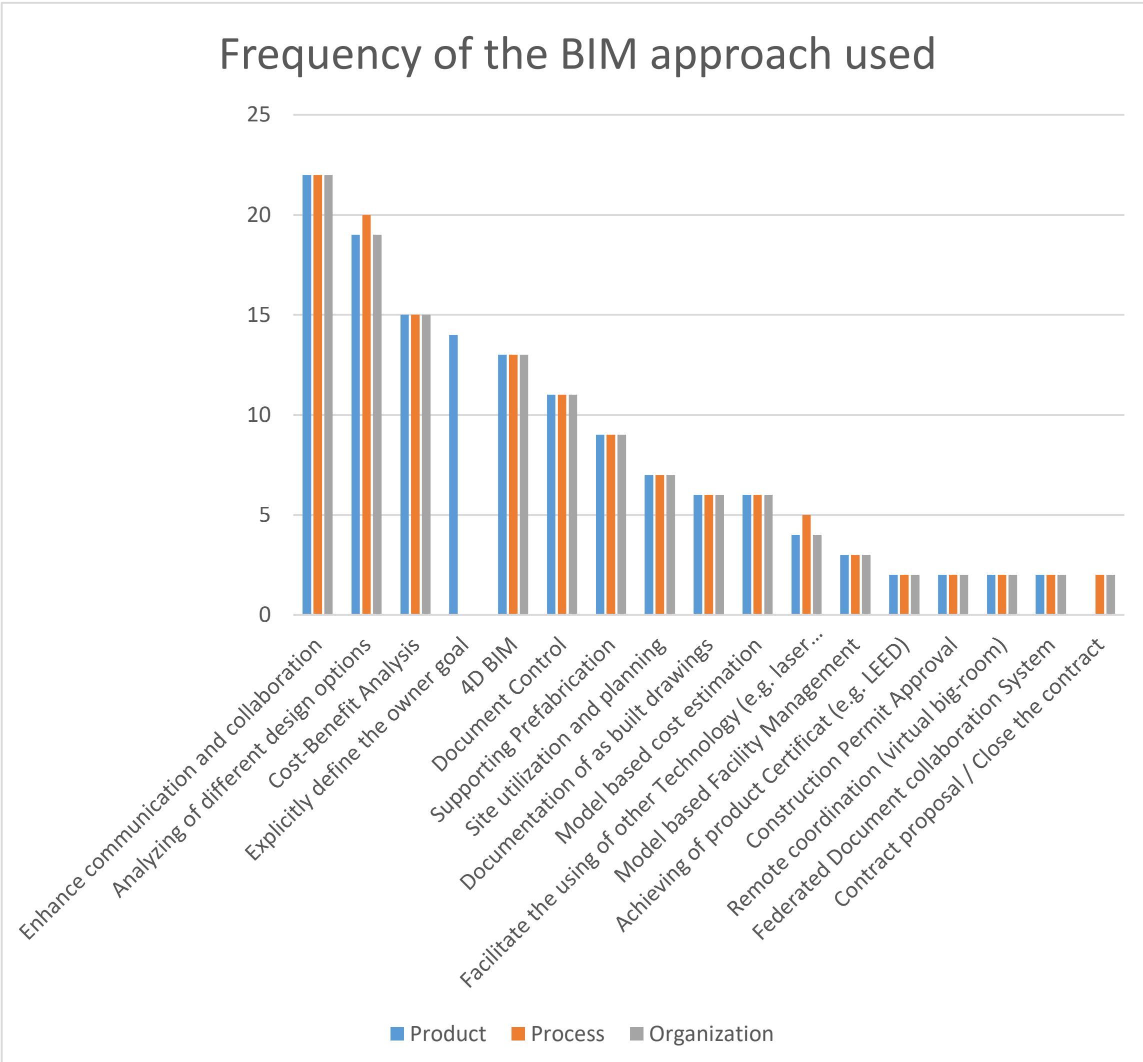


Figure 8 - Frequency of the BIM approach used

- Enhance communication and collaboration
- Analyzing of different design options
- Explicitly define the owner goal
- Cost-Benefit Analysis
- 4D BIM
- Document Control

- Supporting Prefabrication Design and construction
- Site utilization and planning
- Documentation of as built drawings
- Model based cost estimation
- Facilitate the using of other Technology (e.g. laser scanning, 3D printing)
- Model based Facility Management
- Achieving of product Certificate (e.g. LEED)
- Construction Permit Approval
- Remote coordination (virtual big-room)
- Federated Document collaboration System
- Contract proposal / Close the contract

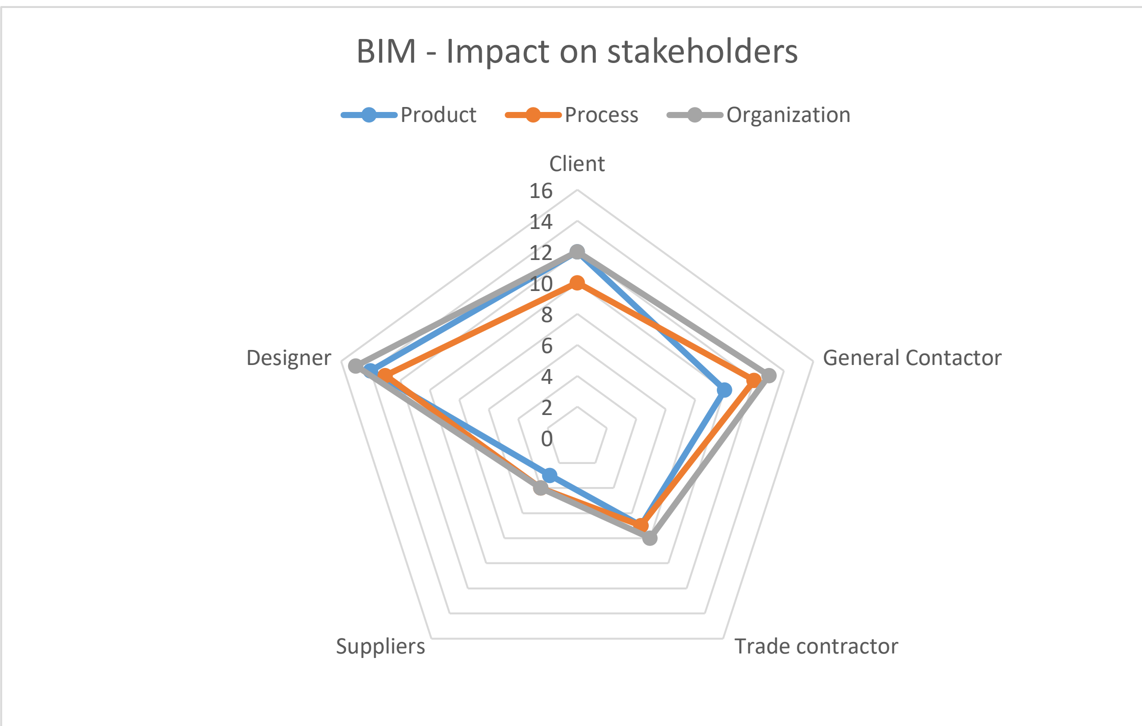


Figure 9 - BIM - Impact on stakeholders

It is also explained in figure 8 with the corresponding impacts on the process, Products, and Organization. Those findings of the model are relevant to benefits which are provided to the project stake holders and they are also drawn in figure 9 in order to enhance the visualization of the benefits and to make it less hard to do a comparison. The BIM benefits are not limited to this only seventeen benefits but those seventeen are the most frequently mentioned in the study cases, Figure 9 also discuss who get the benefit of the impacts and as shown in the figure the Designer, General Contractor, and the Client are the main beneficiaries of the BIM-Implementation.

5.6.Analysis of Lean Impacts

In this section the impact of Lean will be analyzed in tabular form (*Table 7*) on the project (Product, Process, and Organization). Group clustering of the use of the model was done, and the corresponding impact of the model on the three levels which are stated above was recorded with the corresponding cases which are listed below of each impact. There is also one cell at the end which state benefit to whom in order to know who is the stakeholders party get the benefit (it is not a must that the stakeholder who will use the model to have the benefit, but what was recorded is, in some cases one party of the model users will get the benefit, and in some cases all the users will get benefits, and in other cases other party who did not use the model still shear some benefits of the model besides other stakeholders).

Table 7 - Lean Imapct Benefit Analysis

Lean Approach	**Impact on the Project (Product, Process, Organization)** • Product: the impact of the design and the building Quality • Process: impact on managing the sequence and work flow • Organization: impact on engaging the stakeholders in the project		**Who get benefits**
1. Trade Contractors are hired early to participate in early design decision.	Product	The opportunity for error on site was reduced (collaboration between the contractor and the designer lead to a shear of the experiences and information regarding the design prospective and the constructability prospective). Reduction of Time (as the contractor will start working while the design is developed which lead to a big save in time) Reduction on Project Cost (due to the reduction in time which lead on reduction of overhead costs on the project, besides the reduction of the change orders and the uncertainty corresponding with the project)	Client Designer G. C S. Cs Suppliers

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued		Reduction of RFIs and Change Orders (due to the high collaboration on the process)	
		Case Studies No. 2, 5, 6, 7, 8, 14, 15, 17, 18, 19, 20	
	Process	Design process is done with more reliability, and coherence between different trade contractors, and the designer. The Design Process is done in shorter time with a high quality Design Process is not done in the early phase only but, it is done during the whole project Construction process is going in parallel to the design process. The uncertainty related to the process is reduced and the flow of work is increased.	Client Designer G. C T.Cs
		Case Studies No. 2, 5, 6, 7, 8, 14, 15, 17, 18, 19, 20	
	Organization	Collaboration is the main characteristic of this delivery method, more than one party is involved in the design stage and giving a consultation to the designer and the client, meanwhile the overlapping between the design and the construction lead to collaboration between the contract stakeholders	Client Designer G. C T.Cs Suppliers
		Case Studies No. 2, 5, 6, 7, 8, 14, 15, 17, 18, 19, 20	
2. Target Value Design	Product	Design was done in a way which meet the client requirement within the budget which was assigned by the client, no exceed of the target cost.	Client
		Case Studies No. 2, 5, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21	
	Process	The design process is done with a lot of collaboration and a pool for shearing of the information was created to in order to find the other alternatives of the design. Continues improvement was done during the design and the construction. Continues monitoring on the construction site to reduce the waste areas. Collaboration between the project stakeholders to shear ideas, and inform about the waste area.	Client Designer G.C T.Cs

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
		Case Studies No. 2, 5, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21	
	Organization	Designer, client, General Contractor, Trade Contractors, and Suppliers, all of them are engaged in the design options and solution. The designer is the one who lead this collaboration with referencing to the client.	Client Designer G.C T.Cs
		Case Studies No. 2, 5, 6, 7, 8, 12, 14, 15, 17, 18, 19, 20, 21	
3. Continuous planning (weekly & daily) of the task to meet the milestones / Last Planner System (LPS)	Product	The project was delivered without any type of delays. Reduction of waste in material, and productivity (as the material was planned every week, and the learned lesson from before was checked, besides continuous calculation of the actual productivity)	Designer G.C T.Cs
		Case Studies No. 2, 6, 7, 8, 9, 11, 12, 13, 14	
	Process	The schedule was done in a hierarchy way that the master schedule was done with the milestones, meanwhile the design was developed during the construction work and the second level of the schedule which has interval of months was developed, then the third level with week interval was developed, till the fourth level which is daily schedule. Trust and reliability of the construction process was increased	Client Designer G.C T.Cs
		Case Studies No. 2, 6, 7, 8, 9, 11, 12, 13, 14	
Continued	Process	Visualization software of the schedule was used and the weekly plan was able to be visualized. Designer, General Contractor and Trade contractors are engaged from the early phases of the scheduling to the detailed weekly plan.	
		Case Studies No. 2, 6, 8, 12	
	Organization	Collaboration and shearing of information and ideas between the project stakeholders is done during the scheduling. Engaging the front line people in the schedule	Client Designer G.C T.Cs
		Case Studies No. 2, 6, 7, 8, 9, 11, 12, 13, 14	

<table>
<tr><th>Lean Approach</th><th colspan="2">Impact on the Project (Product, Process, Organization)</th><th>Who get benefits</th></tr>
<tr><td rowspan="6">4. 3D Visualization before construction</td><td rowspan="2">Product</td><td>The design is fit for purpose.
Reduction of uncertainty.
Reduction of clashes during the construction.
Better Communication.</td><td rowspan="2">Client
Designer
G.C
T.Cs</td></tr>
<tr><td>Case Studies No. 1, 2, 3, 4, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24</td></tr>
<tr><td rowspan="2">Process</td><td>The final model is an output of an integration of different models (MEP, Architectures, Structure).
Simulation of the construction process is done and the possible ways for material transportation in the site besides the prober location of the cranes and the crane movement, moreover planning of the temporary buildings.
Clash detection is done before construction.
Better communication between the model participants during design and the planning of the pre-construction phase.
Construction process is going more faster (due to the anticipation of the risk and the waste and clashes areas)</td><td rowspan="2">Designer
G.C
T.Cs</td></tr>
<tr><td>Case Studies No. 1, 2, 3, 4, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24</td></tr>
<tr><td rowspan="2">Organization</td><td>More than one model from different discipline are integrated together.
Shear of the project model between the project stakeholders to help in detecting and solving the problem quicker. (Improve collaboration and communication)</td><td rowspan="2">Designer
G.C
T.Cs</td></tr>
<tr><td>Case Studies No. 1, 2, 3, 4, 6, 7, 8, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24</td></tr>
<tr><td rowspan="3">5. IPD method or IFOA Contracts</td><td rowspan="2">Product</td><td>The project is delivered under budget.
The project is delivered within the target quality and time</td><td rowspan="2">Client</td></tr>
<tr><td>Case Studies No. 2, 6, 7, 8, 14</td></tr>
<tr><td>Process</td><td>All the Contract members shear the gains and pains including the client.
The structure of the contract in such a way when there is a profit and the project is under budget the shearing in the profit are divided</td><td></td></tr>
</table>

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued	Process	between the IPD-members including the client, and when the saving in budget is reached certain limit the shearing of the non-owner-IPD is increased. When the project is running over budget the client is the only one pays for this amount. (the risk of the non-owner-IPD is limited to their profit margin which was calculated before.	All the IPD members (Client, G.C, Designer, T.Cs)
		Case Studies No. 2, 6, 7, 8, 14	
	Organization	The main project stakeholders are member of the IPD and all of them is seeking the project to run under budget and with the target quality. Transparency and trust is developed between the project stakeholders.	G.C T.Cs Designers Client
		Case Studies No. 2, 6, 7, 8, 14	
6. Maximize the value of the project by increasing dedication between team members.	Product	The project is delivered under budget and fit for purpose.	Client
		Case Studies No. 2, 5, 14, 15, 17, 18, 19, 20	
	Process	Increase the coordination between the design and the project team (as when facing any problem, the question asked is: who should I ask to solve it? And the focus is on exploring the problem and how to prevent it in the future instead asking who should pay for it?). Maximize the value of the project by creating a coherence between the team members interest and the project. Teach the project team how to think about the benefit of the project not the company.	Client G.C T.Cs Designers
		Case Studies No. 2, 5, 14, 15, 17, 18, 19, 20	
	Organization	Coherence, coordination, and productive working environment is established between stakeholders.	Client G.C T.Cs Designers
		Case Studies No. 2, 5, 14, 15, 17, 18, 19, 20	
7. Location Based Management System (LBMS)	Product	Provide schedule with less number of activities, which increase the readability of the schedule and reduce the opportunity of error.	G.C T.Cs
		Case Studies No. 4, 11, 13, 16, 23	
	Process	The same trade takes the same duration in different locations. By the end of the project there was no buffer noticed. Reporting was done based on	G.C T.Cs

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
Continued		location. Location is the main storage of information and actions. Scheduling process is more clear to visualize the waste, buffer, and risk analysis.	
		Case Studies No. 4, 11, 13, 16, 23	
	Organization	Increase the interaction between the stake holders and manage the flow of the data, create a downstream management (the front line people are represented).	G.C T.Cs Client
		Case Studies No. 4, 11, 13, 16, 23	
8. Long term relation with the suppliers	Product	The service provided is better quality and done faster There is trust and reliability in the relation. The suppliers and the general contractors aims to continuous improvement on the sub products. Lower prices with higher quality and shorter time.	G.C Suppliers Client
		Case Studies No. 5, 18	
	Process	The process is done under more reliability and the willing of investing in improving the process from both parties. Both of parties feeling the responsibility of improving the services and the product. More investment are invested on the improvement of the process and making it more automated	G.C Suppliers
		Case Studies No. 5, 18	
	Organization	In the organization frame trust was implemented. The suppliers are considered a part form the early beginning of the project. Both general contractor and suppliers are coordinated to develop the final product.	G.C Suppliers
		Case Studies No. 5, 18	
9. Using of prefabrication and standardized elements	Product	Better quality is obtained (due to the continuous improvements on the single elements which reflected on the whole product at the end). Reduction of the lead time for insulation (due to the continuous improvement) Reduce the risk of construction (the construction process is changed into insulation process)	G.C T.Cs Client Designer Suppliers

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
		Case Studies No. 2, 6, 12, 15, 17, 18, 19, 20, 24	
	Process	Reduction of the onsite storage area for material. Elimination of the onsite workshops. The process of construction is mostly changed into installation process instead of manufacturing which reduce the corresponding risk related to uncertainty. Geometric dimensions should be double checked	G.C T.Cs Client Designer Suppliers
		Case Studies No. 2, 6, 12, 15, 17, 18, 19, 20, 24	
	Organization	Reduction of the manpower required onsite.	G.C T.Cs Client
		Case Studies No. 2, 6, 12, 15, 17, 18, 19, 20, 24	
10. Pull flow is considered in planning	Product	Reduction in the schedule Reduction of the risk corresponding to material expiry. Reduction of the site mobilization costs (storage areas are reduced)	G.C T.Cs Client
		Case Studies No. 2, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 20, 23	
	Process	The work onsite is structured in such a way to be ordinated with the work which has to be done on the schedule. Reduction of the rework which is produced form the undone takes. Increase of the monitoring and controlling due to small size patches was used.	G.C T.Cs
		Case Studies No. 2, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 20, 23	
	Process	The project is more fixable in terms of changing (trade is done only when approved).	G.C T.Cs Client
		Case Studies No. 2	
	Organization	Reduction of the required area for storage of the materials.	G.C T.Cs
		Case Studies No. 2, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 18, 19, 20, 23	

Lean Approach	Impact on the Project (Product, Process, Organization)		Who get benefits
11. Automation	Product	The building is delivered with less error and the opportunity of improvement is increased. The quality and the expectation of the final product meet the planned (big reliability)	G.C T.Cs Designers Client Suppliers
		Case Studies No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24	
	Process	The process in the beginning is not that fast as the traditional one (most of the technology used in the construction now are quite new and not a lot of people has experience in it, and that require a learning time). But after the first stage which is estimated to be around three months the process is done faster with more reliability.	G.C T.Cs Designers Client Suppliers
		Case Studies No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24	
	Organization	The organization frame is changed with the automations due to the capability of engaging deferent people from remote place in the decision making. Reduction of the manpower onsite. The system need to be organized in such way to help in the improvement of the learning curve and the learning lesson need to be emphasized.	G.C T.Cs Designers Client Suppliers
		Case Studies No. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24	

Legends	
G.C	General Contractor or the Main Contractor of the Projects
T.Cs	Trade Contractors or the sub-Contractors
Suppliers	The party which provide supply of the material or some services
Client	This term represent the owner weather it is a single party or a joint venture
Designer	The party which is responsible for providing the design (regardless to the discipline)

5.7. Findings of Lean Impacts

As a result of this study, the implementation of BIM in Lean environment can be clustered into elven different groups (the lean impacts in the construction industry is not limited to those eleven groups, but those eleven groups are the main findings in the case studies which were frequently repeated), also the studies where take into consideration the BIM is implemented in order to achieve reduction in cost and time of the project, the Lean findings could be listed as indicated in *figure 10* and can be stated with sorting of the most frequently used tool as:

- Automation
- 3D Visualization before construction
- Pull flow is considered in planning

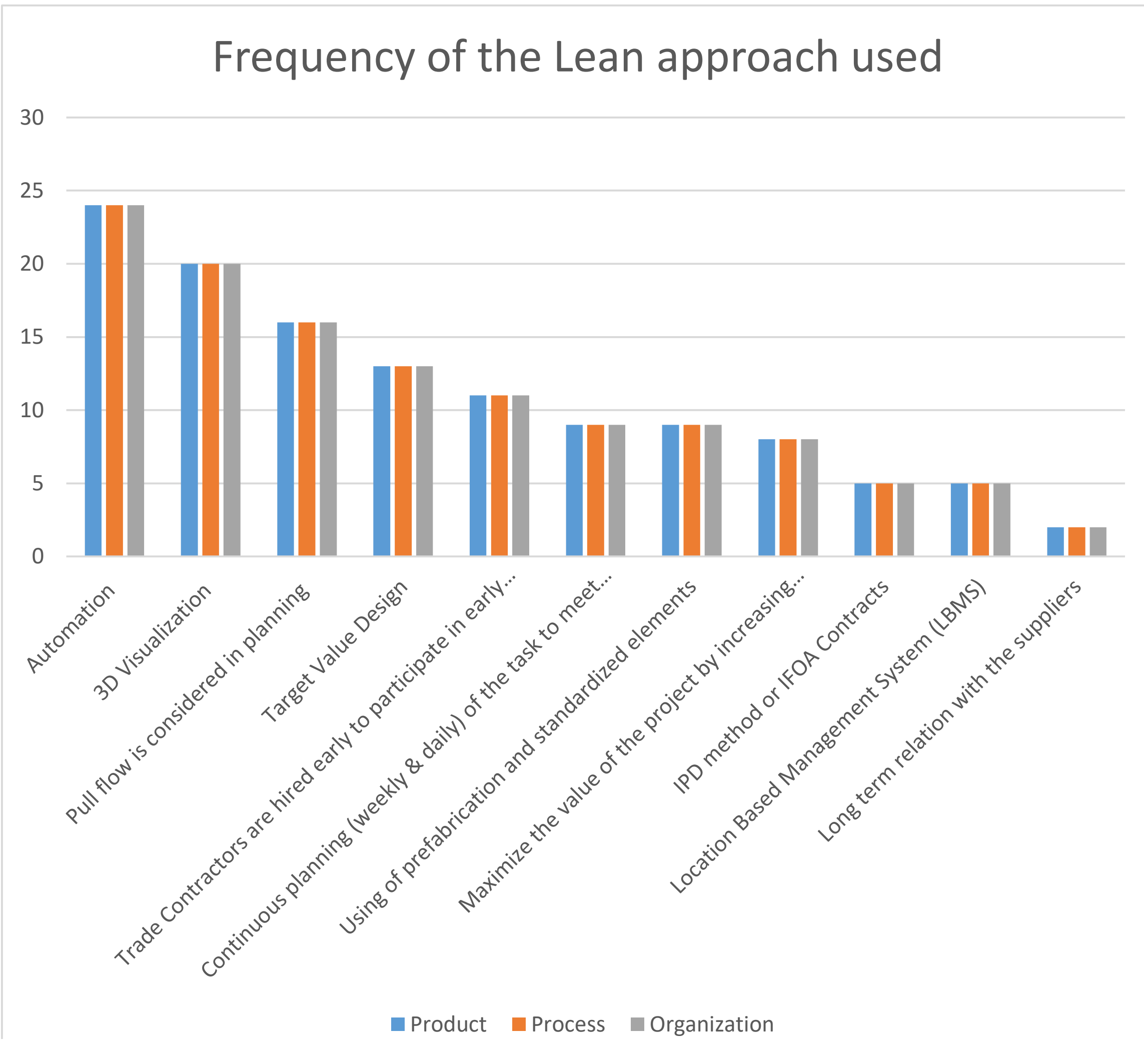


Figure 10 - Frequency of the Lean approach used

- Target Value Design
- Trade Contractors are hired early to participate in early design decision
- Continuous planning (weekly & daily) of the task to meet the milestones / Last Planner System (LPS)
- Using of prefabrication and standardized elements
- Maximize the value of the project by increasing dedication between team members
- IPD method or IFOA Contracts
- Location Based Management System (LBMS)
- Long term relation with the suppliers

In figure 11 it is demonstrated the benefits on the stakeholder and as we can see most of the stake holder get equal benefits of implementing the Lean environment.

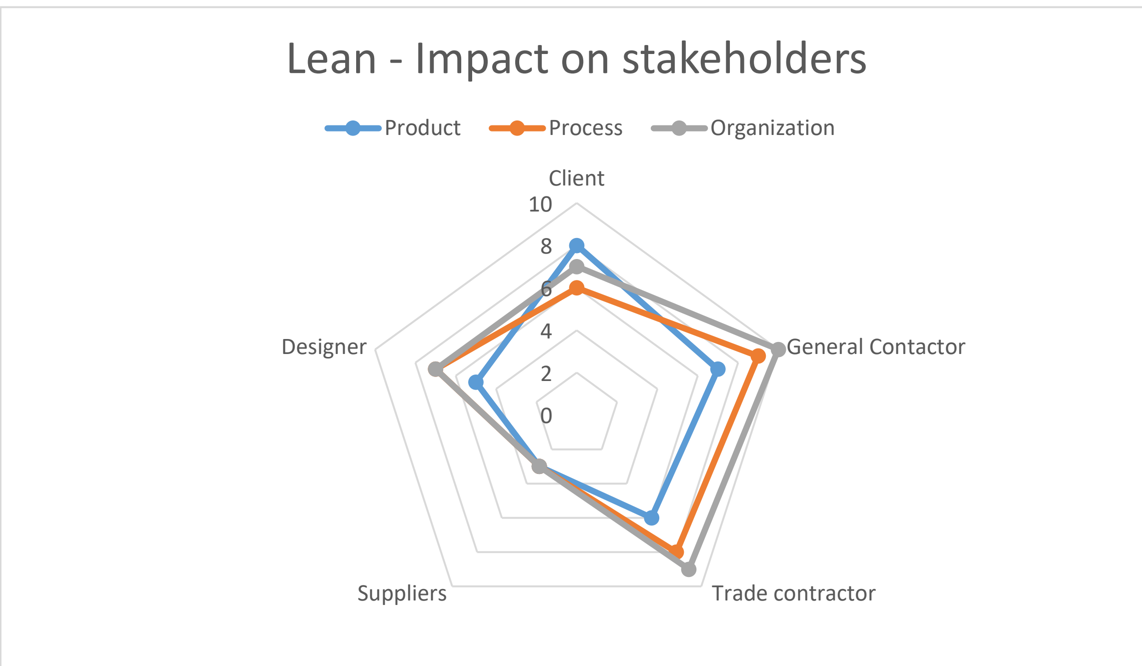


Figure 11 - Impact on stakeholders

6. BIM-Lean Implementation Roadmap

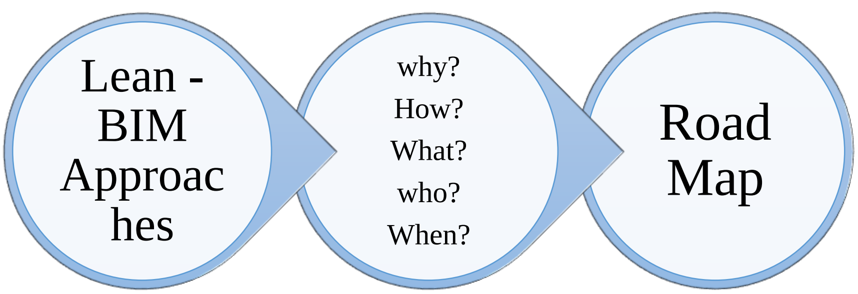
Chapter 5 – BIM-Lean Implementation plan will present the proposed structure and the main guidelines for the Implementation of BIM in a Leaner environment in the construction industry. This chapter is based mainly on the literature review which was conducted earlier and also on the cases studies analysis findings.

The proposed plan (Framework) is not limited to an ad hoc project. the main idea behind this plane is to be used to help in formulating a process for different projects. As a project is defined in PMBOK project is a Temporary, Unique, with progressive Elaboration [131]. Which lead to a conclusion of, avoidance of developing any specific process (process is done to suite in specific moment with specific circumstances), but the framework will be used as a guidance in producing different processes.

6.1.Framework Developing Approach

As a result, from the literature and the analysis part, it can be stated that the Lean in construction industry is the environment which needed to be established in the project in order to lead a success of the project, and the BIM is the tool to achieve the modern success of the project.

In order to formulate an idea about the frame 5 question will be asked (Why? How? Who? What? When?)



[131] (Pm 2000), P. 7-9

Towards answering the question what? There was a research carried out in order to define what? to measure and recommend some KPIs, according to Collin (2002) [132] in order to define a KPI there are a number of sets which needed to be taken into consideration while developing the KPI:

a. KPI is made to measure the performance from certain aspect outputs or outcomes.
b. The KPI need to be simple in using and not a time consuming task, having to many and complex KPIs will shift the KPI purpose form a performance measurement tool into a burden on the project team.
c. Data collection required should be as simple as possible.

Before the beginning of the five question analysis, some bases for the time needed to be set to indicate when, the analyzed tool or technique will be used. It is possible to group it into four groups as what indicated in the following *Table 8*.

Table 8 - Time Groupping

Feasibility & Concept Develop	Design Develop & Design Document	Pre-Construction & Construction	Operation

The stake holders also will be grouped into five main groups (Client or owner, General Contactor (G.C), Trade Contractors (TC) or Subcontractors (S.C), Suppliers, and Designer).

In order to achieve the frame work, five main areas of analysis were defined. Three project initiations (Cost, Time, and Quality). And two Crosswalks (Enhancing the communication and collaborations, and Waste Management).

while studying the outcomes of the case studies it was noticed that the approaches of Lean used could be classified into three main areas: 1. Culture. 2. Techniques & Tools. 3. Organization.

[132] (Collin 2002)

6.2.BIM – Lean Freamework Developing and Analysing.

In this section the findings will be analyzed and discussed according the five questions which were stated earlier in the previous section.

1. **Reduction of construction cost.** (*initiation*)

Why?

As a matter of fact, at the construction stage most of the project money is spent. Which acquire an indeed effort to reduce the cost.

Who?

In order to achieve a proper cost reduction, all the project stakeholders should be involved; which mean the involvement of the Client, Designer, General Contractor, Trade Contractors, and the suppliers.

Also the integration of the working people for every party in order to make a big use of the learning curve during the processing of the task or a product.

When?

Reduction of cost should start form the early stages of the project, from the feasibility stage (as the degree of freedom in this stage is very high) and till the end of the construction stage, also it could be extended to the operating stage for the use of facility management.

How?

Regarding to what was investigated in the cases studies chapter, reduction of waste could be achieved by the use of BIM features as long with Lean-tools.

From the data out put some revolutionary tools will be used to do the reduction of the cost overrun.

a) Maintain a long relation with the suppliers, as that helps in having a better communication medium, and better cost on the long run relation.
b) Increase the dedication between the team members by involving them in the relevant decision, that will be accomplished in the best way by the use of last planner system
c) Standardization of the objects and using a pre cast element.
d) Pull flow planning, as it was recorded of having a great impact on the reduction of the storage space on site and reduction of material waste, Increase of the monitoring and controlling due to small size patches was used, besides the reduction of rework required to complete the task, (the tusk is not lunched only when it is required).
e) 3D visualization before construction, number of benefits were recorded form the visualization before the construction; helping in understanding the client objective of the facility, as that reduce the number of the change orders during the construction and helping in orientating the client objective, moreover, that reduce the conflict between the different stakeholder of the project in the early phase of the work and help every stakeholder in forming a comprehensive understanding of the project and also adding there comments, precautions, and limiting conditions on the project before the implementation of the project. Simulation of the construction process is done and the possible ways for material transportation in the site besides the prober location of the cranes and the crane movement, moreover planning of the temporary buildings. Construction process is going faster (due to the anticipation of the risk and the waste and clashes areas).
f) Target Value Design, as design was done in a way which meet the client requirement within the budget which was assigned by the client, no exceed of the target cost. The design process is done with a lot of collaboration and a pool for shearing of the information was created to in order to find the other alternatives of the design. Continues improvement was done during the design and the construction. Continues monitoring on the construction site to reduce the waste areas. Collaboration between the project stakeholders to shear ideas, and inform about the waste area.
g) Model based cost estimation, this BIM feature helps in exploring different scenarios faster and with an accurate data output, which lead of having better cost for the similar facility function.

h) Trade Contractors are hired early to participate in early design decision, great impact was recorded form the cases studies which was investigated earlier and the review of literature, e.g., reduction of the cost due to the experiences of the trade contractor in the material used and the work procedures.

i) IPD method or IFOA Contracts, the main project stakeholders are member of the IPD and all of them is seeking the project to run under budget and with the target quality.

What?

To answer this question, need to define what to measure, so some KPIs needed to be defined. In a pursue of defining a cost performance and based on prior research in the same field a lot of papers and a lot of cases have considered the variation between the current cost and the planned cost as the main indicator of performance, e.g. Ling, et al. have defined the Cost Performance as an indicator of a comparison between the actual and the budgeted cost of the project [133]. Moreover, Chan and Chan have concluded "*Cost can be measured in terms of unit cost, percentage of net variation over final cost*"[134]. Key performance indicators for this initiation can be measured by deploying the use of net present value (NPV), net cash flow (NCF). And to a better control for the using of those performance indicators there is an indeed need for the use of Location based management system (LBMS) by measuring and reporting those indicators related to the relevant area.

2. **Reduction of construction Time.** (*initiation*)

Why?

Construction projects are mainly depending on the time, cost and the quality. So time is one of the main target of the project stakeholder is to deliver the project as soon as possible to deploy it to the operating and using stage.

Who?

All the project stakeholders are playing a role in the project time and all of them are having an influence on the project time either this influence was direct or indirect.

[133] (Ling, et al. 2008)
[134] (Chan and Chan 2004)

Moreover, the two level of details of the stakeholders (Macro which is represented in top management, or Micro which is represented in front line people) both of them having a great impact on the project running time.

When?

In a pursue of having a less project time and reduction of the project running time, this initiation should start form the early phase (feasibility) as the project at this stage has a big degree of freedom and a lot of decisions could be done which are relevant to the time of the project.

How?

As a result of the literature review and of the cases studies analysis some guild lines could be recommended to help in the reduction of the project time, starting from the contracting until the handing over of the project, these guidelines could be stated as:

1. IPD method or IFOA Contracts; as this type of contract provide the environment to integrated all of the stakeholders in the decision making regarding the project and all the stakeholders are shearing pain and gain of the project which laying at the end in the success of the project in terms of cost, time, and quality. Moreover, this type of contract functions the best when integrated with Design-Build method.
2. Trade Contractors are hired early to participate in early design decision; this technique enrich the time planning stage of the project as the trade contractors gives a prober information about the productivity of the trades, and also suggest different construction method if it will lay in the benefit of the project in terms of costs and time savings with a fit for purpose quality. Moreover, hiring the trade contractor form the beginning reduce the number of change orders which is time and money consuming process.
3. Pull flow is considered in planning: considering this technique in the planning of the project, has documented to deliver a lot of value to the project and be a main reason of time reduction of the project as it reduces the buffer time in the planning,

and also reduce the amount of rework by the end of the project which is a time and cost consuming task.

4. Using of prefabrication and standardized elements; the use of standardized elements, was documented to have a big impact on the project schedule, due to reduction of the time which is required to carry over the task on site comparing with the traditional method.
5. Maximize the value of the project by increasing dedication between team members; increase dedication between the team members, was documented form the cases study its good impact on the project in terms of time and money.
6. Continuous planning (weekly & daily) of the task to meet the milestones / Last Planner System (LPS); the use of this technique form a front back management which helps in providing a real indication of the productivity of the project and making a precis and realistic plan of the project, all of the cases which were studied in this research get benefited from the use of LPS.
7. Using BIM for enhancing communication and collaboration; the use of BIM in communication helps in reducing and in some cases eliminating the miss understanding and the Requests for Information (RFI) which is a time consuming task, and also helps to reduce or eliminate the error in construction which is also time consuming task.
8. 4D – BIM; the use of 4D BIM offers the planner a lot of options during the planning stage form the simulation of the construction, the mobilization plan of the project, and also was documented that it helps in reduction of the planning error which is produced due to miss assigning the predecessors and successors relation. Moreover, it provides the user a full visualized 3D project with the relevant data assigned to each member of the project, which lead to an easy access of the project information.
9. Using BIM for clash detection; the use of this BIM feature is reducing the time consumed in doing the clash detection by the traditional way which is about laying a different project plans over each other and doing the detection by some persons who are supposed to be experts in clash detection. Moreover, the use of BIM is more accurate than the traditional way which lead by the end to reduce or eliminate any construction clashes.

10. Using BIM for documentation of as built drawings; the use of BIM increases the reliability of the as built drawing and reduce the time consumed in this process.
11. Using BIM Analyzing of different design options; the use of BIM reduces the time consumed for the design analysis and also increases the option of analysis of more alternatives.

What?

In order to answer what question, there is a need to define a KPIs. There are a lot of KPIs where defined to time e.g. Ling, et al. have stated Schedule performance is a comparison made between the actual and planned duration for the project. Time performance would be improved if timing of acceptance, approval, and commitment of the schedule by the project team is early, firms have few monitoring activities to detect cost overruns and the likelihood of being engaged by client or project team members in future is high [135]. Also one recommended tool of the LPS (which is the lean planning tool) this tool is Percent *Plan Complete (PPC)*: percent plan complete is the monitoring tool which is used in the weekly work plan, it is a gauge divide the work done by the work planned (did/will), and used as an indicator to measure the work performance of this week.

3. Quality *(initiation)*

Why?

Quality of the project is one of the main target of the project stakeholders, and one of the main definition of quality is that fit for purpose.

When?

Quality is done mainly starting from the design stage to the construction stage, but to have a better output of the project it is highly recommended to start planning the quality from the feasibility stage.

[135] (Ling, et al. 2008)

Who?

In order to achieve the target quality, there is an indeed need for the participation of the all project stake holders in this initiation. And also the stake holder with its two level (Macro which is represented in management, Micro which is represented in the front line people).

How?

Regarding to the investigation which was done, some tools and features can be used to assure the achievement of a certain quality:

a) Cost benefit analysis; doing cost benefit analysis explore different project options form the design prospective or constructability of the project. Moreover, doing cost benefit analysis helps the client in forming a comprehensive picture about the project and the target quality of it. The use of BIM is highly recommended in this stage due to the number of benefits which is driven from the visualization tool of BIM and the options of exploring the different options easier than the traditional way, and less time consuming.
b) Model based cost estimation; as a matter of fact, the quality is having a direct and strong link with the cost, by representing the data on the BIM platform (the element liked to its corresponding costs) that helps the user to form a full understanding of the impact of the quality on cost, and also helps in having a better quality with a similar budget.
c) Maximize the value of the project by increasing dedication between team members; by increasing the dedication between team members the waste done in the project execution stage is reduced which lying in the benefit of the project quality and the project cost.
d) Enhancing the communication and collaboration; the better communication tool is used the more reliable and higher quality transfer of information are provided.
e) Long term relation with the suppliers; maintain a long term relation with the suppliers helps in better communication, besides it provides the opportunity to the supplier to improve the products.
f) Pull Flow; as a matter of fact, pull flow helps in reducing the size of the patch which give the project team the option of better control on the quality.

g) Location Based Management System (LBMS); LBMS helps in providing better control on the quality of the project.

What?

Quality in construction industry is rather subjective. Quality is fitness for Purpose. However, to achieve the demanded quality there is a need to go into processes of the standards which was defined either by the region norms or by the project team during the project early phases. As the main aim of the project is to convince the end users to purchase or use the facility and the quality is the mean to achieve this target.

Providing KPIs to quality is totally subjective process and differ from one project to another, there is no room for a generalization of a certain guidelines to be implemented in different construction project. Which lead to a conclusion of a need for a task in which framework should be defined for the project and this framework should be structured in such way to go along with the project phases and section, and to provide a full control on the target quality.

4. Enhance communication and collaboration. *(Process)*

Why? – *increase the transparency, collaboration, and control*

Construction industry is full of members, in some cases according to the Kamppi case study which was stated earlier in the chapter 4 in some site there were around 800 T.Cs and Suppliers [136]. And the aim of this card is to enhance the communication and collaboration between the project stake holders (Internal, and External).

Who? – *internal and external*

Communication and collaboration could be divided into (internal and external). External is done between the project five parties which is stated above and internal is done with the one party members, and Internal is done in the realm of one party and in two levels as well (communication between the management and the stuff, communication between the stuff itself).

[136] (Kenley and Seppänen 2009)

How? - *BIM, LPS, and LBMS*

To develop a communication plane it has to be done in two levels of communication: strategic level and operational level.

Strategic level: at this level the main question is how to implement a communication plan to help the project to achieve its strategic goal (linking the communication to the project strategy and to the value added to the project).

Operational level: is focusing about how to provide communication channels, and the quality of management and communication.

To improve the communications, three parallel techniques were found two is from lean and the other one is from BIM backgrounds, and they are (Location Based Control System, Last planner system, and Visualization), both tools will be used in the three communication levels.

External Communications – the BIM model will be integrated into the communication channels between the project stake holders to make sure of the visualization of the 3D and also for schedule, cost, and in the operation phase.

Internal communication – this area could be divided into two communications levels one is communication between the management and the stuff, the second is communication between the same level of the stuff, Last planner system will be used to manage the communication and the planning via Daily-Weekly-Monthly meetings & reporting. Besides the use of BIM but BIM is recommended to be used under a certain level of authorization of the users, to avoid any miss in data, or over flow of information (as it was noticed in the case studies the over flow of information is producing uncertainty) which is not relevant for the users. Which lead to conclude the need of the use of LPS and BIM in a hierarchy level of the flow of information.

What?

To answer what it is needed to investigate some KPIs to do measurement. Measurement of communication is totally subjective, meaning of successful communication is to deliver the idea clearly and smoothly between different stakeholders.

Which lead to define KPIs related to the reduction of number of Requesting for Information (RFI). And reduction in number of Change Orders.

5. **Waste Management** *(process)*

Why?

Establishing the waste tracking culture in the project was found to be one of the main tools for success of the project. Waste is routed into the industry for long time, and it is one of the main reasons for reduction of productivity within the projects.

When?

Starting the waste tracking or Waste Management should be form the early beginning of the project. From the feasibility stage to the end of construction stage and may continue to the operation stage if the project time frame is extended to the operational stage.

Who?

In order to achieve an efficient Waste Management plan, there is an indeed need for the participation of the all project stake holders in this initiation. And also the stake holder with its two level (Macro which is represented in management, Micro which is represented in the front line people).

How?

Waste roots in construction industry can be broken down into three main areas: process related, technology related, and policy related. Process is about the technique and the sequence of work. also it is about how to integrate all the available resources to get the optimal use of it, a process is a specific ordering of work activities across time and place, process is about the flow the more flow maintained the more output gained. Technology is about implementation of knowledge between the interaction between the human been and the software or machines to achieve the project target. Policies are the rules for providing a good working environment it includes also education, contracts, regulations, standards, and guidelines.

Furthermore, regarding to this research some tools could be recommended to help in implementation of an efficient waste management plan;

a) Establishment of the tracking waste culture in the project, from the project top management to the front line peoples.

b) Using of BIM in quantity take off, as BIM provides the users with an updated and accurate quantity take off.

c) Just in time procurement schedule to reduce the storage space and material waste.

d) Management is not centralized but everyone should take a part in the management plane.

e) Material should be touched twice one time at the suppliers and the second during the installation.

f) Helping the Client in formulating a clear and vivid targets and visions of the project. That can be achieved by the implementation of Integrated Project Delivery method (IPD). Besides, the use of BIM software in visualization of the final product and the project stages.

g) Enhancing the communication within the project by using BIM software and implementing of the Lean-tools.

7. Conclusion and Recommendation

The integration of BIM and Lean are the main elements to overcome the waste main adversities (Organization, Process, Technology). As BIM is the Technological tool, and Lean is Process, and Organization tool. The use of BIM alone is more or less changing from 2D drawing into 3D drawing, which is still a good change but not a great achievement.

This research lead to conclusion of; BIM is the technology which will be used to accomplish the project target (reduce the waste and add value to the final product). And lean is the environment which needed, in order to get the benefits of the using of this technology otherwise the technology alone will not help.

In the main conclusion part answer for the first two question was provided, and in the recommendation part answer for the third question was mentioned.

7.1.Conclusion

How BIM and Lean impact the Project (Product, process, Organization)?

BIM has a big impact on the project, according to the results recorded the case studies and the review of the literature. BIM Increase the efficiency within the project through optimizing the project Product, Process, and Organization. Seventeen different uses of the model were recorded;

1. Enhance communication and collaboration.
2. Analyzing of different design options.
3. Supporting of Cost-Benefit Analysis.
4. Explicitly define the owner goal.
5. Visualization of the schedule (4D BIM).
6. Document Control.
7. Supporting Prefabrication.
8. Site utilization and planning.
9. Documentation of as built drawings.
10. Model based cost estimation.

11. Facilitate the using of other Technology (e.g. laser scanning, 3D printing). 12. Model based Facility Management.
12. Achieving of product Certificate (e.g. LEED).
13. Construction Permit Approval.
14. Remote coordination (virtual big-room).
15. Federated Document Collaboration System.
16. Contract proposal / Close the contract.

The adoption of Lean tools within the Project, have a great impact on the waste management system of the project. Although Lean was found to be more of a cultural thing than a set of tools to be used. This research has come up with results of different lean approaches used, to Increase the efficiency within the project through optimizing the project Product, Process, and Organization. Eleven different approaches of lean using and understanding were recorded;

1. Adoption of automation.
2. Pull flow is considered in planning.
3. 3D Visualization before construction.
4. Target Value Design.
5. Trade Contractors are hired early to participate in early design decision.
6. Continuous planning (weekly & daily) of the task to meet the milestones / Last Planner System (LPS).
7. Using of prefabrication and standardized elements.
8. Maximize the value of the project by increasing dedication between team members.
9. IPD method or IFOA Contracts.
10. Location Based Management System (LBMS).
11. Long term relation with the suppliers.

Who from the stakeholders benefit from BIM and Lean?

The benefits of BIM or Lean on the stake holders were found to depend on the project (Product, Processes, and Organization). Who gets the benefit of the use of BIM, that depends mainly on who is driving the use of the model. But according to the results of this thesis, the party who get the most of the benefits of the use of the BIM is the Designer with (15) benefits for the Organizational structure, (14) on the Product, and (13) On the Working Processes. The second Party benefited of BIM is the General Contractor with (13) benefits for the Organizational structure, (10) on the Product, and (12) On the Working Processes. Then comes the client on the third stage with (12) benefits for the Organizational structure, (12) on the Product, and (10) On the Working Processes. Afterwards, comes the Trade Contractor in the fourth stage with (8) benefits for the Organizational structure, (7) on the Product, and (7) On the Working Processes. Finally, comes the supplier in the fifth stage with (4) benefits for the Organizational structure, (4) on the Product, and (3) On the Working Processes [137].

The results which were recorded form the investigation of Lean on the different stake holders. Indicated that, the General Contractor is the party who gets the most benefits of adoption of Lean in the project with (10) benefits for the Organizational structure, (7) on the Product, and (9) On the Working Processes. Then following with the Trade Contractor with (9) benefits for the Organizational structure, (6) on the Product, and (8) On the Working Processes. At the third stage comes the Client with (7) benefits for the Organizational structure, (8) on the Product, and (6) On the Working Processes. Afterwards comes the Designer with (7) benefits for the Organizational structure, (5) on the Product, and (7) On the Working Processes. Finally, comes the supplier with (3) benefits for the Organizational structure, (3) on the Product, and (3) On the Working Processes.

7.2.Recommendations

In the recommendation section the main answer to the third research question (How could a roadmap be developed, to integrate BIM and Lean in construction projects?) is provided.

1. The recommended project delivery method was found to be; Integrated Project Delivery (IPD). As the stakeholder will get the most use of BIM, and also there are a lot of benefits

[137] (x) x = number of cases recorded in the case study analysis section.

discussed in this thesis (e.g., great impact on the reduction of project Cost, Organization, and process waste).

2. Maximize the value of the project by increasing dedication between team members. As a matter of fact, the human being act as one of the main elements towards the success of the project, transparent collaboration between the working personal is required to achieve the project target.
3. Investment in learning and educating the working staff. Not only to learn the new technology BIM, but also to understand the concept and the idea behind it. And why is BIM used to facilitate the work.
4. Defining of KPIs for the project main area, and making sure this KPIs is simple in using and also simple in data aggregation method.
5. Using of a small patch size in the project, that helps in better monitoring and controlling.
6. Standardization of the project section during the construction. Breaking the project down into similar areas (e.g., standard construction method for offices, or kitchen, or corridors). Assigning those section to different teams, and making sure that the same team who constructed the same section will construct it in the next floor. As that help in mastering the learned lessons for every team.
7. Reduce the response time in the process, and reduce the no. of the process to produce any task. The increase in number of processes affect the quality. As every single process has a certain yield the more processes are involved the less yield will be achieved.
8. Diffusing of risk anticipation culture.
9. While the Designing of the construction Building there should be a process for Construction planning.
10. A combination of pull and push system is found to be the most efficient way in managing, as Push system is deployed in the early phases to mitigate the time risk due to uncertainty related to the project (push system is recommended to be deployed in preparing the site document, preparing the delivery orders, doing some work on site which has to be done in any case and the work will not be damaged from a long wait after being finished). Other than that, pull system is highly recommended to be used.

Declaration of Authorship

I hereby declare that the attached Master's thesis was completed independently and without the prohibited assistance of third parties, and that no sources or assistance were used other than those listed. All passages whose content or wording originates from another publication have been marked as such. Neither this thesis nor any variant of it has previously been submitted to an examining authority or published.

23-08-2017

Date Signature of the student

8. References

Aibinu, Ajibade, and Sudha Venkatesh. 2014. "Status of BIM adoption and the BIM experience of cost consultants in Australia." *Journal of Professional Issues in Engineering Education and Practice* (American Society of Civil Engineers) 140.

Aliaari, M, and E Najarian. 2013. "Sutter Health Eden Medical Center: structural engineer's active role in an IPD project with lean and BIM components." *Struct. Mag* 32-34.

2014. "Analysis of the implementation of effective waste management practices in construction projects and sites." *Resources, conservation and recycling* (Elsevier) 99-111.

Arayici, Y, P Coates, Lauri Koskela, Mike Kagioglou, C Usher, and K O'reilly. 2011. "Technology adoption in the BIM implementation for lean architectural practice." *Automation in Construction* (Elsevier) 20: 189-195.

Arditi, David, and H Murat Gunaydin. 1997. "Total quality management in the construction process." *International Journal of Project Management* (Elsevier) 15: 235-243.

atz, Amnon, and Hadassa Baum. 2011. "A novel methodology to estimate the evolution of construction waste in construction sites." *Waste management* (Elsevier) 353-358.

Azhar, Salman. 2011. "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry." *Leadership and management in engineering* (American Society of Civil Engineers) 11: 241-252.

Baik, Ahmad. 2017. "From Point Cloud to Jeddah Heritage BIM Nasif Historical House--case study." *Digital Applications in Archaeology and Cultural Heritage* (Elsevier).

Ballard, G. 2000. "LCI White Paper 8: Lean project delivery system. Lean Construction Institute." *Lean Construction* (Lean Construction Institute) 1-15.

Ballard, Glenn. 2008. "The Lean Project Delivery System: An Update." *Lean Construction Journal* 1-19.

Ballard, Glenn, and Lauri Koskela. 1998. "On the agenda of design management research." In *Proceedings IGLC.*

Ballard, Glenn, and Paul Reiser. 2006. "The St. Olaf College Fieldhouse project: a case study in designing to target cost." In *12th annual conference of the International Group for Lean construction*, 234-249.

Ballard, Herman Glenn. 2000. *The last planner system of production control.* University of Birmingham.

Bertelsen, Sven, Guilherme Henrich, Lauri Koskela, and John Rooke. 2007. "Construction physics."

Björk, Bo-Christer, and Mikael Laakso. 2010. "CAD standardisation in the construction industry—A process view." *Automation in Construction* (Elsevier) 19: 398-406.

Boggs, Charles M. 2010. "Mock-ups in design: the implications of utlizing [sic] a mock-up review process in professional practice."

Boorstin, Daniel Joseph. 1978. *Republic of technology: reflections on our future community.* Harper and Row, Publishers, Inc., New York, NY.

Chan, Albert PC, and Ada PL Chan. 2004. "Key performance indicators for measuring construction success." *Benchmarking: an international journal* 203-221.

Chandler Jr, Alfred D. 1993. *The visible hand.* Harvard University Press.

—. 1993. "The visible hand." Harvard University Press.

Collin, J. 2002. "Measuring the success of building projects--improved project delivery initiatives." *Report for the Queensland Department of Public Works, Australia.*

Dave, Bhargav, Lauri Koskela, Arto Kiviniemi, Robert L Owen, and Patricia Tzortzopoulis Fazenda. 2013. "Implementing lean in construction: Lean construction and BIM-CIRIA Guide C725."

Davenport, T.H. 2013. *Process innovation: reengineering work through information technology. Harvard Business Press.* Harvard Business Press.

dos Santos, Aguinaldo. 1999. *Application of flow principles in the production management of construction sites.* University of Salford.

Eastman, Charles M, Chuck Eastman, Paul Teicholz, and Rafael Sacks. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* John Wiley \& Sons.

—. 2011. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors.* John Wiley \& Sons.

Eastman, Charles. 1975. "The use of computers instead of drawings in building design." *AIA Journal.*

2010. "Exploring critical success factors for waste management in construction projects of China." *Resources, conservation and recycling* (Elsevier) 201-208.

Fernandez-Solis, Jose L, Vishal Porwal, Sarel Lavy, Ali Shafaat, Zofia K Rybkowski, Kiyoung Son, and Nishi Lagoo. 2012. "Survey of motivations, benefits, and implementation challenges of last planner system users." *Journal of construction engineering and management* 354-360.

Formoso, Carlos T, Lucio Soibelman, Claudia De Cesare, and Eduardo L Isatto. 2002. "Material waste in building industry: main causes and prevention." *Journal of construction engineering and management* 128 (4): 316-325.

Formoso, Carlos T, Lucio Soibelman, Claudia De Cesare, and Eduardo L Isatto. 2002. "Material waste in building industry: main causes and prevention." *Journal of construction engineering and management* (American Society of Civil Engineers) 316-325.

Ganah, AA and John, Godfaurd Adjaie. 2014. "Achieving Level 2 BIM by 2016 in the UK." In *Computing in Civil and Building Engineering (2014)*, 143-150.

Gangolells, Marta, Miquel Casals, N Forcada, and Marcel Macarulla. 2014. "Analysis of the implementation of effective waste management practices in construction projects and sites." *Resources, conservation and recycling* 93: 99-111.

Gao, Ju, and Martin Fischer. 2008. *Framework and case studies comparing implementations and impacts of 3D/4D modeling across projects.* Stanford University CA.

Gao, Shang, and Sui Pheng Low. 2014. "The Toyota Way model: an alternative framework for lean construction." *Total Quality Management \& Business Excellence* (Taylor \& Francis) 25: 664-682.

Gunasekaran, Angappa, Chaitali Patel, and Ercan Tirtiroglu. 2001. "Performance measures and metrics in a supply chain environment." *International journal of operations & production Management* 71-87.

Guy, H. 2007. "Design-build and trenchless—A perfect solution!" In *Pipelines 2007: Advances and Experiences with Trenchless Pipeline Projects*, 1-7.

Hammer, Michael. 1990. "Reengineering work: don't automate, obliterate." *Harvard business review* 104-112.

Hamzeh, Farook Ramiz. 2009. *Improving construction workflow-The role of production planning and control.* University of California, Berkeley.

Hamzeh, Farook, Glenn Ballard, and Iris D Tommelein. 2012. "Rethinking Lookahead Planning to Optimize Construction Workflow." *Lean Construction Journal.*

Hardin, Brad, and Dave McCool. 2015. *BIM and construction management: proven tools, methods, and workflows.* John Wiley \& Sons.

Hastings, Jessica and Kibiloski, John, Martin Fischer, John Haymaker, and Kathleen Liston. 2006. "Four-dimensional modeling to support construction planning of the Stata Center project." *Leadership and Management in Engineering* (American Society of Civil Engineers) 3: 86-94.

Hines, David. 2013. "Interoperability in Sports Design." *Architectural Design* (Wiley Online Library) 70-73.

Ho, Samuel KM, and Christopher KH Fung. 1994. "Developing a TQM excellence model." *The TQM Magazine* (MCB UP Ltd) 6: 24-30.

Innes, S. 2004. *Proceedings of Minimising Construction Waste Conference: Developing Resource Efficiency and Waste Minimisation in Design and Construction.* New Civil Engineer London.

Jaillon, L, Chi-Sun Poon, and YH Chiang. 2009. "Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong." *Waste management* 29 (1): 309-320.

Jaillon, L, Chi-Sun Poon, and YH Chiang. 2009. "Quantifying the waste reduction potential of using prefabrication in building construction in Hong Kong." *Waste management* (Elsevier) 309-320.

Jiang, Shen, and Wang Lei. 2017. "The Application of BIM in Green Building Energy Saving: Take Helsinki Music Center as an Example." In *Advanced Materials Research*, 3-7. Trans Tech Publ.

Jones, S. 2014. *"Rececnt SmartMarket BIM research," McGraw Hill Construction.* January 08. Accessed Jun 04, 2017. https://c.ymcdn.com/sites/www.nibs.org/resource/resmgr/BSA/20140108_moa_jones.pdf.

Jones, SA, and HM Bernstein. 2012. "The Business Value of BIM in North America." *Smart Market Report* 68.

Kalsaas, Bo Terje. 2012. "The last planner system style of planning: its basis in learning theory." *Journal of Engineering, Project, and Production Management* (Association of Engineering, Project, & Production Management) 2: 88.

Katz, Amnon, and Hadassa Baum. 2011. "A novel methodology to estimate the evolution of construction waste in construction sites." *Waste management* 31 (2): 353-358.

Kenley, Russell, and Olli Seppänen. 2009. *Location-based management for construction: Planning, scheduling and control.* Routledge.

Kent, David C, and Burcin Becerik-Gerber. 2010. "Understanding construction industry experience and attitudes toward integrated project delivery." *Journal of construction engineering and management* 815-825.

Khanzode, Atul, Martin Fischer, and Dean Reed. 2008. "Benefits and lessons learned of implementing building virtual design and construction (VDC) technologies for coordination of mechanical, electrical, and plumbing (MEP) systems on a large healthcare project." *Journal of Information Technology in Construction (ITcon)* 324-342.

Koskela, Lauri, and others. 2000. *An exploration towards a production theory and its application to construction.* VTT Technical Research Centre of Finland.

2007. "The TFV theory of production: new developments." In *Proceedings of 15th International Group for Lean Construction Conference*, by Lauri Koskela, John Rooke, Sven Bertelsen and Guilherme Henrich.

Kymmell, Willem. 2007. *Building Information Modeling: Planning and Managing Construction Projects with 4D CAD and Simulations (McGraw-Hill Construction Series): Planning and Managing Construction Projects with 4D CAD and Simulations.* McGraw Hill Professional.

Lawton, Ted, P Moore, Ken Cox, and John Clark. 2002. "The gammon skanska construction system." In *Proceedings of the International Conference Advances in Building Technology*, 1073-1080.

2002. "The gammon skanska construction system." In *Proceedings of the International Conference Advances in Building Technology*, by Ted Lawton, P Moore, Ken Cox and John Clark, 1073-1080.

Lee, Ghang, Harrison Kwangho Park, and Jongsung Won. 2012. "D 3 City project—Economic impact of BIM-assisted design validation." *Automation in Construction* (Elsevier) 22: 577-586.

Lee, Ghang, Rafael Sacks, and Charles M Eastman. 2006. "Specifying parametric building object behavior (BOB) for a building information modeling system." *Automation in construction* (Elsevier) 15: 758-776.

Lewis, MA, and N Slack. 2003. "An introduction to general themes and specific issues." *Operations Management: Critical Perspectives in Management. Routledge, London.*

Lewis, MA, and N Slack. 2003. "An introduction to general themes and specific issues." *Operations Management: Critical Perspectives in Management. Routledge, London.*

Ling, Florence Yean Yng, Swee Lean Chan, Edwin Chong, and Lee Ping Ee. 2004. "Predicting performance of design-build and design-bid-build projects." *Journal of construction engineering and management* (American Society of Civil Engineers) 130: 75-85.

Ling, Florence Yean, Sui Pheng Low, ShouQing Wang, and Temitope Egbelakin. 2008. "Models for predicting project performance in China using project management practices adopted by foreign AEC firms." *Journal of Construction Engineering and Management* (American Society of Civil Engineers) 134: 983--990.

Liu, Shijing, Benzheng Xie, Linda Tivendal, and Chunlu Liu. 2015. "Critical barriers to BIM implementation in the AEC industry." *International Journal of Marketing Studies* 7: 162.

Lu, Qiqi, Jongsung Won, and Jack CP Cheng. 2016. "A financial decision making framework for construction projects based on 5D Building Information Modeling (BIM)." *International Journal of Project Management* (Elsevier) 34: 3-21.

Lu, Weisheng, and Hongping Yuan. 2010. "Exploring critical success factors for waste management in construction projects of China." *Resources, conservation and recycling* 55 (2): 201-208.

Miettinen, Reijo, and Sami Paavola. 2014. "Beyond the BIM utopia: Approaches to the development and implementation of building information modeling." *Automation in construction* (Elsevier) 43: 84-91.

Miller, John B, Michael J Garvin, C William Ibbs, and Stephen E Mahoney. 2000. "Toward a new paradigm: Simultaneous use of multiple project delivery methods." *Journal of Management in Engineering* (American Society of Civil Engineers) 58-67.

Mossman, Alan. 2013. "Last Planne: crucial & collaborative conversations for predictable design & construction delivery." *The Change Business Ltd., UK.*

Nahmias, Steven, and Ye Cheng. 2009. *Production and operations analysis.* New York: McGraw-Hill/Irwin New York.

Newton, Kym, and Nicholas Chileshe. 2012. "Awareness, Usage and Benefits of Building Information Modelling (BIM) Adoption--The Case of the South Australian Construction Organisations." *Management* 3: 12.

O'Keeffe, Aonghus. 2014. "The State of the Art of Bridge Information Modelling from Conceptual Design through to Operation." *International Journal of 3-D Information Modeling (IJ3DIM)* (IGI Global) 29-39.

Olano, Ricardo M, Luís F. Alarcón, and Carlos Rázuri. 2009. "Understanding the relationship between planning reliability and schedule performance—A case study." *Proc., 17th Annual Conf. of the Int. Group for Lean Construction (IGLC-17).*

Osmani, Mohamed, Jacqueline Glass, and Andrew DF Price. 2008. "Architects' perspectives on construction waste reduction by design." *Waste Management* (Elsevier) 1147-1158.

Palmberg 5D BIM Case Study, Vico. 2015. *Palmberg 5D BIM Case Study.* Accessed Jun 18, 2017. http://www.vicosoftware.com/0/Community/Case_Studies/Palmberg-Verma-Salmisaari-5D-BIM.

Park, Jane, and Young Hoon Kwak. 2017. "Design-Bid-Build (DBB) vs. Design-Build (DB) in the US public transportation projects: The choice and consequences." *International Journal of Project Management* (Elsevier) 3: 280-295.

Pikas, Ergo, Lauri Koskela, Stelios Sapountzis, Bhargav Dave, and Robert Owen. 2011. "Overview of building information modelling in healthcare projects."

Pm, I. 2000. *A guide to the project management body of knowledge (PMBOK guide).* Project Management Institute.

Poksinska, Bozena, Dag Swartling, and Erik Drotz. 2013. "The daily work of Lean leaders--lessons from manufacturing and healthcare." *Total Quality Management & Business Excellence* 886-898.

Riese, Martin. 2008. "One Island East, Hong Kong: a case study in construction virtual prototyping." *Virtual futures for design, construction & procurement* (Blackwell Publishing Ltd.) 59-71.

SAWYER, TOM, and TIMOTHY GROGAN. 2002. "FINDING THE BOTTOM LINE GETS A GRADUAL LIFT FROM TECHNOLOGY COMPLEX TASK IS NO EASY FIT FOR SOFTWARE DEVELOPERS." *ENR* 26.

Seppänen, O and Kankainen, Jouko. 2004. "Empirical research on deviations in production and current state of project control." In *Annual Conference of the International Group for Lean Construction*.

Simchi-Levi, David, Edith Simchi-Levi, and Philip Kaminsky. 2003. *Designing and managing the supply chain: Concepts, strategies, and cases.* McGraw-Hill New York.

Solutions, Autodesk Building Industry. 2002. *Building Information Modeling.* Online.

Succar, Bilal. 2009. "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in construction* 18 (3): 357-375.

Succar, Bilal. 2009. "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in construction* (Elsevier).

Sun, Chengshuang and Jiang, Shaohua, Miroslaw J Skibniewski, Qingpeng Man, and Liyin Shen. 2017. "A literature review of the factors limiting the application of BIM in the construction industry." *Technological and Economic Development of Economy* (Taylor \& Francis) 23: 764-779.

Thompson, DB, and Ryan G Miner. 2006. "Building information modeling-BIM: Contractual risks are changing with technology." *WWW document] URL http://www. aepronet. org/ge/no35. html.*

Vico Case study, Online. 2014. *"Kamppi Center Project," Vico.* Accessed Jun 18, 2017. http://www.vicosoftware.com/69126/0/Community/Case_Studies/SRV-Group-Kamppi-Center.

Vico Office Takeoff Manager™. 2017. *Vico Office Takeoff Manager™,.* Accessed April 6, 2017. http://cdn2.hubspot.net/hub/658/file-4154101029-pdf/docs/takeoff-manager-(print).pdf?t=1466757978000.

Vierula, Minna, and others. 2015. "Sustainability in the planning of urban courtyards: case: Varma, new properties in Helsinki." (Lahden ammattikorkeakoulu).

Volk, Rebekka, Julian Stengel, and Frank Schultmann. 2014. "Building Information Modeling (BIM) for existing buildings—Literature review and future needs." *Automation in construction* (Elsevier) 109-127.

Wang, Jiayuan, Hongping Yuan, Xiangping Kang, and Weisheng Lu. 2010. "Critical success factors for on-site sorting of construction waste: a China study." *Resources, Conservation and Recycling* 54 (11): 931-936.

Wang, Jiayuan, Hongping Yuan, Xiangping Kang, and Weisheng Lu. 2010. "Critical success factors for on-site sorting of construction waste: a China study." *Resources, Conservation and Recycling* (Elsevier) 931-936.

Williams, M. 2011. "Building-information Modeling Improves Efficiency, Reduces Need for Changes." *Business Journal, USA.*

Williams, M. 2011. "Building-information Modeling Improves Efficiency, Reduces Need for Changes." *Business Journal, USA.*

Willis, Carol, and Donald Friedman. 1998. *Building the empire state.* WW Norton \& Company.

Womack, James P, Daniel T Jones, and Daniel Roos. 2007. *The machine that changed the world: The story of lean production, Toyota's secret weapon in the global car wars that is revolutionizing world industry (New Ed.).*

Won, Jongsung, and Jack C.P. Cheng. 2017. "Identifying potential opportunities of building information modeling for construction and demolition waste management and minimization." *Automation in Construction, 79* 3-18.

Wu, Wei, and Raja RA Issa. 2013. "BIM education and recruiting: Survey-based comparative analysis of issues, perceptions, and collaboration opportunities." *Journal of professional issues in engineering education and practice* (American Society of Civil Engineers) 140.

Yin, Robert K. 1994. "Discovering the future of the case study method in evaluation research." *Evaluation practice* (Elsevier) 2: 283-290.