Project Optimisation Through the Combination of BIM and Last Planner System

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STUDENT REPORT

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Abstract

This report consists of a systematic review examining the aspects of BIM and LPS; specifically, how BIM can benefit the use of LPS, which is the research question. In order to find the answer of the research question, three sub questions are considered.

The first research question concerns the contribution of BIM to Lean Construction, how the BIM functionalities interact with the Lean principles. The second research question highlights which BIM functionalities have higher impact on the benefits of LPS among all the listed functionalities, why communication of information is important in construction and how it can be improved. Lastly, the last research question refers to the development of a process that integrates the use of BIM combined with LPS, to be used for the implementation or as a step of CDP for a system development.

Preface

This report is conducted as a part of the fourth semester of the master's program in Management in the Building Industry, at Aalborg University. It was conducted during the time span from the 1st of February 2018 to the 8th of June 2018.

I would like to express gratitude for all the help through valuable comments and advices received from my supervisor of the thesis, Kjeld Svidt.

Reading guide

Throughout the report, references in the form of the Harvard method will be used, with additional information listed in the bibliography. References from books, articles, websites etc., will appear with the surname of the author and the year of publication in the form of "(Surname, Year)" or "Surname (Year)". The latter will be used if the reference is used actively in the text. If the reference is not placed within the same sentence, it refers to the whole paragraph. Otherwise, it only refers to the respective sentence.

Figures and tables are numbered according to their respective chapter, meaning that the first figure in chapter 2 has number 2.1, the second, number 2.2 and so on. Explanatory text is found under the given figures and tables. Figures and tables without references are elaborated by me.

Mario García Burguete

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List of Abbreviations

BIM	Building Information Modelling
CD	Contextual Design
CDP	Contextual Design Process
CMAR	Construction Management at Risk
DB	Design-Build
DBB	Design-Bid-Build
HVAC	Heating, Ventilating and Air Conditioning
IoT	Internet of Things
IPD	Integrated Project Delivery
LoB	Line-of-Balance
LPS	Last Planner System
MEP	Mechanical, Electrical and Plumbing
O-MI	Open-Messaging Interface
RFI	Request for Information
RFID	Radio Frequency Identification
VDC	Virtual Design and Construction
WIP	Work in Progress

Report Structure

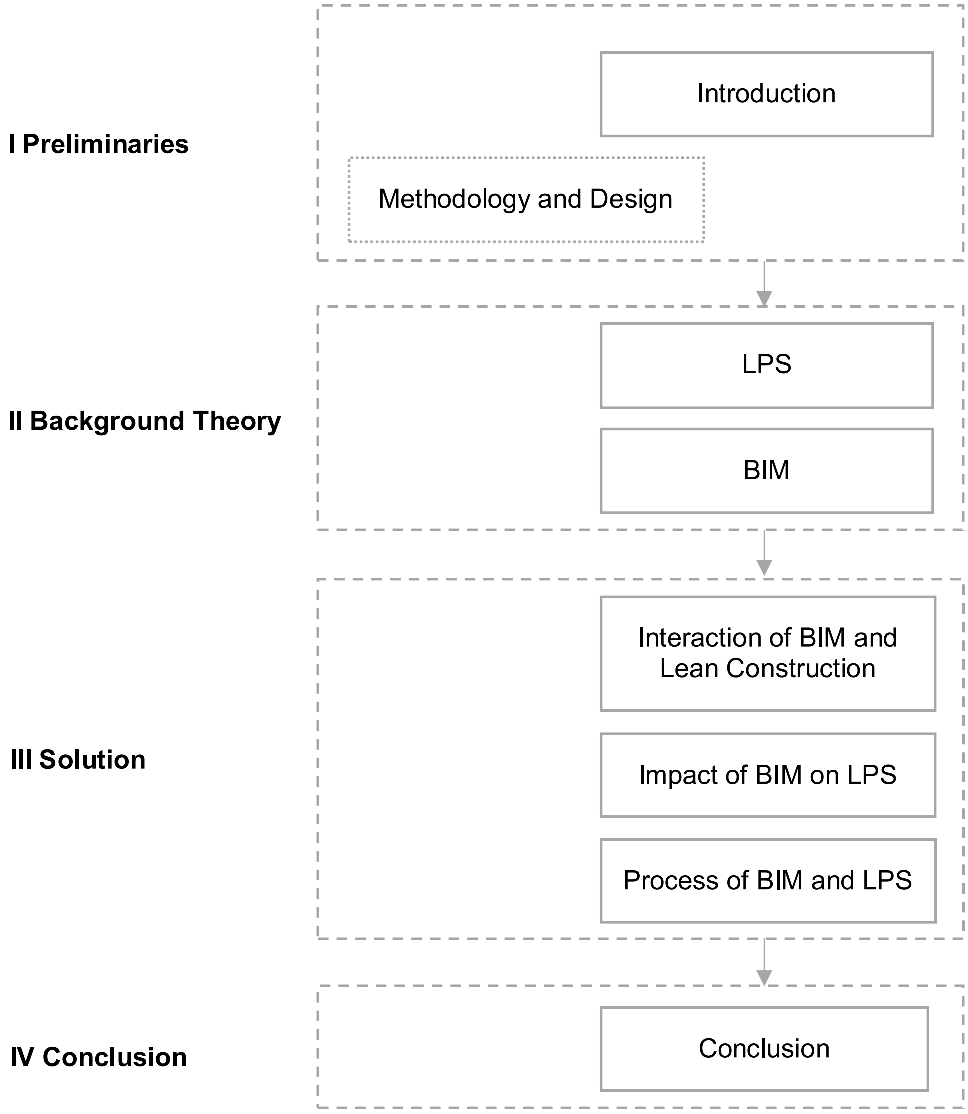

Figure 0.1 Structure of the report.

This report is divided explicitly in four parts as it is shown in Figure 0.1. The first part contains the introduction, where it starts with the background of the topic in order to make the reader familiar with it. Furthermore, it will formulate the research questions which will guide the later development of the report. Methodology and Design chapter is also included in the first part, it is where the chosen research design and methods are stated and explained.

The second part provides the theoretical background needed to be able to answer the research questions and give the reader the sufficient knowledge for understanding the following part of the report. This background theory is based on the two main topics of the thesis; BIM and LPS.

The third part consists of the results of the report. It incorporates the different chapters where the later stated research questions are analysed and answered based on the different data collected through the methods in the second and third part.

Lastly, the fourth part contains the conclusion where the results that answer the research questions are summarised and stated. Last part will also contain the reflection and the bibliography stating all the references used during the report.

PART I. PRELIMINARIES

1. Introduction

Throughout this chapter, it will be given an introductory overview about the content of this study. It is divided in the background, the aim of the research and the subsequent research questions.

1.1. Background and Research Questions

During the last decades, the building construction industry has remained relatively low efficient, even with the application of many advanced technologies (Koushki, et al., 2005). These new technologies have failed in its attempt of reducing the cost of the design and the construction and enhancing the management of the construction project (Teicholz, 2004).

Lean construction philosophy has been claimed to increase the productivity. It brings the concepts and principles from Toyota Production System to the construction industry. The bases of Lean construction are waste reduction, continuous improvement and increasing the value. (Sacks, et al., 2010)

One of the main reasons of the decrease of the construction productivity refers to the lack of coordination between the different subcontractors (Mincks & Johnston, 2010). The lack of coordination and collaboration causes problems and errors during construction which requires waste of time and money for solving them. Lean construction procedures require successful coordination and collaboration between the general contractor and the subcontractors to ensure that the work is performed without waste. Last Planner System (LPS) is a Lean construction tool that attempts to solve this problem; and therefore, adds reliability to the work plan.

Moreover, Building Information Modelling (BIM) is a technological tool that also has potential to avoid errors coming from poor coordination and collaboration and helps achieving the Lean principles as Sacks, et al. (2010) elaborated in his study about the interactions between Lean and BIM. Several contractors have taken advantage of implementing Lean and BIM simultaneously, after the success of implementing Lean and BIM as two separates actions (Fosse, et al., 2017).

As a response to these construction problems, the aim of this thesis is to investigate how can these two tools, BIM and LPS, be complemented in order to optimise the project results. The aim is to research on the contribution of BIM to Lean during construction in order to later analyse the contribution of BIM to LPS as a narrower area. Moreover, to examine the BIM functionalities that have the biggest impact on LPS. Lastly, to develop the process of the combination of these tools. In order to be able to investigate all these areas and be used as a guideline to be answered during the research, one research question with its corresponding three sub questions will be stated in the following:

- How can BIM benefit the use of LPS?
    - How can BIM contribute to Lean in the construction phase?
    - Which BIM functionalities have higher impact on LPS and how are they applied?
    - How can the process that integrates LPS with the use of BIM be developed for a later implementation or system development?

2. Methodology and Design

This chapter will discuss the research design and the methodology used in the report. Moreover, the reliability and validity will also be included in the chapter.

2.1. Research Design

The research design must be chosen before the method of collecting data since the research design defines the structure of the report that has to be followed. The research design has to ensure that the results answer the research questions. (De Vaus, 2001)

Literature review has been chosen as the main research design. This design includes the existing knowledge, the findings and the theoretical contributions to a topic which in this case, the topic would be the interaction between BIM and LPS (Lamb, 2014). Among several types of literature review, systematic review is used in this report because the review focuses on the formulated research question which is the following; how can BIM benefit the use of LPS? It tries to identify, select and analyse the relevant literature in order to answer the research question. (Bolderston, 2008)

The different steps of doing a literature review can be linked to Bloom's revised taxonomy of cognitive domain. (Shields & Rangarjan, 2013) (Granello, 2001) This taxonomy is composed of six parts which will be explained in the following.

- **Remembering**; in this stage, relevant literature such as books or articles are identified and read.
- **Understanding**; the second stage corresponds to the understanding of the literature, might be challenging because of the technical terminology. It is necessary to understand in order to get knowledge to be able to write about.
- **Applying**, it is when the researcher can connect the literature together.

- **Analysing**, all the collected information can be organised and separated into parts. Therefore, the researcher is able to analyse and see how each little part of the literature fits in the big picture.
- **Evaluating**, during this stage, all the information is evaluated regarding its strengths and weaknesses.
- **Creating**, this stage consists of the creation of new knowledge through the literature by the researcher. Some other research questions or gaps in the literature can be identified; moreover, new connections can be made.

The last part of Bloom's taxonomy would correspond to the Part III, called Solution, shown in Figure 0.1. It is where the creation takes place. This new knowledge creation is originated through the literature and the formulation of other research subsections in other to fill the gaps in the literature.

Because of the tough process of executing a literature review, an organisation plan was carried consisting of classifying and ordering all the articles, books and materials in several folders depending on its particular topic. When an organisation system can be applied, it is easier to track all the literature. (Shields, 2000)

2.2. Methods

Qualitative document analysis is the only method used for collecting data in this report. It is a secondary research method because the data is not collected directly from the researcher, instead the data was already existing. The qualitative data has been collected mainly from existing research articles and books. Moreover, some other sources like websites, dissertations etc., were also used.

The different articles were extracted from AAU library, in the Scopus database. Some other conference papers were obtained through their website like the International Group for Lean Construction (IGLC).

2.3. Reliability and Validity

The reliability refers to the repeatability of the results of the report. Reliability depends on whether the research is qualitative or quantitative. In a quantitative research, it is easy to achieve because of the objectivity of the measures. Whereas in qualitative research, it is harder to meet because of the subjectivity of the researcher, the concepts can be measured with different results among researchers. This means that the results of different reports would be different. (Bryman, 2012)

I have tried to achieve the reliability by using the most reliable sources. However, the report might have its reliability a bit compromised because of the subjectivity of qualitative researches.

According to Bryman (2012), validity provides reliability at the same time. This means that reliability is a requirement for being valid. In qualitative research, validity is about the integrity of the conclusions.

In order to a have a valid report; firstly, I achieved the reliability by collecting reliable data from several reliable sources. Secondly, I provided integrated conclusions on the report through using a systematic review with its appropriated methods to collect and analyse the data. However, the use of more methods could have enhanced the validity.

PART II. BACKGROUND THEORY

3. Contract Types

This chapter will introduce and give the characteristic of the different types of contract in the Construction Industry, in order to understand how they can be related to BIM and Lean.

There have been three dominant types of procurement methods which are the following; Design-Bid-Build (DBB), Design-Build (DB) and Construction Management at Risk (CMAR). Moreover, a fourth one called Integrated Project Delivery (IPD) is emerging as being fully adapted to BIM. Since BIM potential of improving its use depends on how well and in which stage the collaboration of the project team is implemented. Each of the building procurement will be explained in more detail in the following.

3.1. Design-Bid-Build

DBB model is represented when the client hires separately the designer and the general contractor with separated contracts. The designer is in charge of developing the building requirements, schematic design, design and contract documents. The designer hires subconsultants to elaborate specialised parts of the design like structure, HVAC etc. The drawing must be coordinated and detailed enough for ease construction bids. The contractor elaborates the cost estimation through a quantity survey from the specification and drawings sent from the designer and the bids from subcontractors. The cost of these estimations is around 1% of the total estimation. Next step is when the client and the designer choose a contractor from the bids, usually the lowest price. In order for the contractor to start the work, they have to analyse the drawings and to plan the construction process with its phases. Inconsistency, inaccuracy and uncertainty in design, new client requirements, previously unknown errors etc. produce errors in the construction phase that has to be resolved by the project team. It might end in legal disputes causing extra costs and delays. Commissioning corresponds to the last step when the building is handed out after ensuring that the building works properly. (Eastman, et al., 2011)

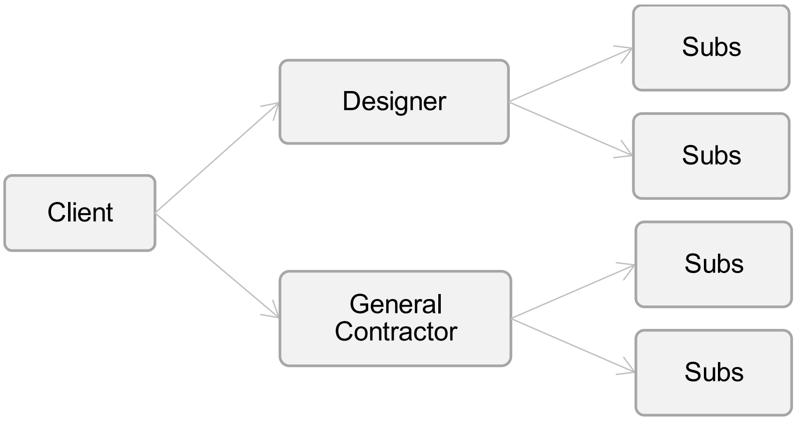

Figure 3.1 DBB.

3.2. Design-Build

DB model is to have contract relation with only one entity who is responsible for both design and construction. This facilitates the client the administration of the project. The client hires the DB contractor, after the building requirements and the schematic design that is required by the client, the contractor prepares the time and cost estimation for the construction and the modifications of the project by the client are executed. Lastly, the DB contractor prepares the budget for the client´s approval. For the specialised work, the DB contractor creates the contracts for both subconsultants and subcontractors. A benefit from this model is that the modification of the project can be made at an early stage which saves time and money. Moreover, the project is made faster because the construction work can be started before all the detailed design drawings are completed. However, once the design is approved, it is hard for the owner to have any change in the design. BIM is highly recommended on this model. (Eastman, et al., 2011)

Figure 3.2 DB.

3.3. Construction Management at Risk

In CMAR method, the client hires separately a designer and a construction manager who provides services for the preconstruction and construction phase. The construction manager prepares the bidding process, planning and cost control of the project and the construction administration. The cost of the project is guaranteed by the construction manager. The benefits of this model are the reduced client's risk and the early inclusion of the constructor.

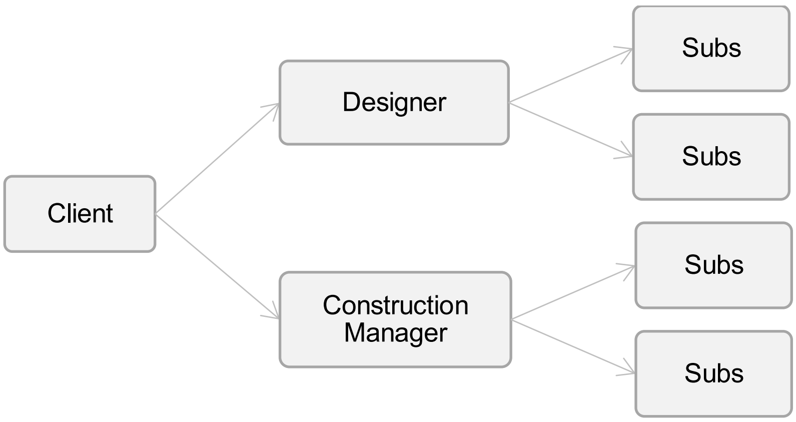

Figure 3.3 CMAR.

3.4. Integrated Project Delivery

IPD is a procurement process that consists of an effective collaboration among the participants of the project. It starts at an early stage and goes all through till the handover phase. By this collaboration the owner will better get his requirements with a lower time and cost. BIM supports IPD and represents a rupture from the traditional paper-based approach. (Eastman, et al., 2011)

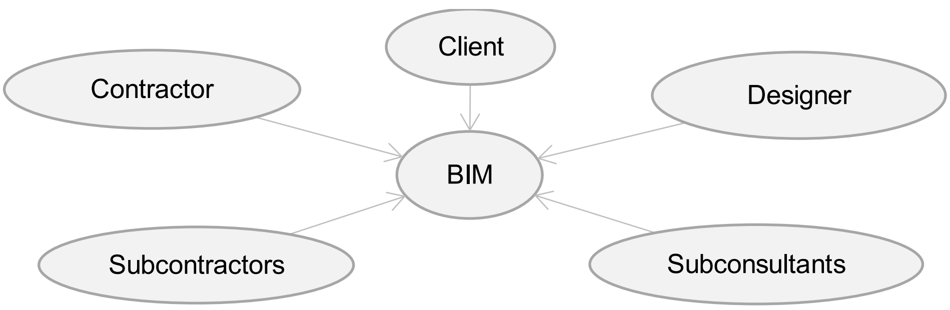

Figure 3.4 Integrated Project Delivery.

4. Lean

Throughout this chapter, it will be given an overview of the origins and the concepts of Lean Construction. Moreover, some important aspects of Lean will also be explained in detail along the chapter.

4.1. Lean Production

Lean production was created by Toyota, specially by its Engineer Ohno. The term “Lean” was coined in 1990 by Womack et al, and it refers to a form of Toyota’s production system which consists of waste elimination. Ohno focused on the whole production system. The objectives were to produce cars meeting the client requirements, deliver them on time and keeping no inventories. The concepts incorporate the following. (Howell, 1999)

- Remove anything that does not add value.
- Continuous flow.
- Perfect the product by stopping the line and pulling inventory.
- Transparency of the production system.

	Conventional Production Philosophy	**New production Philosophy**
Conceptualisation of production	Production consists of conversions, all activities are value-adding.	Production consists of conversions and flows; there are value-adding and non-value-adding activities.
Focus of control	Cost of activities.	Cost , time and value of flows.
Focus of improvement	Increase of efficiency by implementing new technology.	Elimination of non-value adding activities, increase of efficiency of value-adding activities through continuous improvement and new technology.

Table 4.1 Comparison between traditional and Lean production. (Koskela, 1993)

The differences between the traditional production system and Lean production were displayed in Table 4.1. The main difference consists of the activity focus of the traditional production against the activity and flow focus of the Lean production philosophy.

4.2. Lean Construction

Lean construction is attributed to the adaptation of the Lean production principles from Toyota to the construction industry. It is based mainly on waste reduction, continuous improvement and increasing the value. (Sacks, et al., 2010)

Koskela created a theory of production called TFV theory, in which the production can be explained with three concepts; transformation, flow and value generation. Koskela explained that the traditional production in construction focuses only in the transformational view and neglects the flow and value generation views of his theory. This causes the reduction of productivity and quality. Whereas in his theory all three concepts must been taken into consideration to achieve Lean construction. (Koskela, 2000) Table 4.2 displays the three concepts of TFV theory with its respective explanation.

	Transformation view	Flow view	Value generation view
Conceptualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfilment of his requirements
Main principle	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Associated principles	Decompose the production task Minimize the costs of all decomposed tasks	Compress lead time, reduce variability, simplify, increase transparency and flexibility	Ensure that: 1) all require-ments get captured, 2) the flow down of customer requirements, 3) require-ments for all deliverables are taken into account,4) the cap ability of the prod-uction system, and 5) measure the value
Methods and practices (examples)	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, Quality Function Deployment
Practical contribution	Taking care of what has to be done	Taking care that what is un-necessary is done as little as possible	Taking care that customer requirements are met in the best possible manner

Table 4.2 TFV views on production from Koskela. (Sardén & Stehn, 2005)

According to Koskela (1993), construction differs from manufacturing in three main aspects which are the following:

- Unique project.
- Different site construction.
- Different organisations over the time.

However, Lean principles can still be applied to improve the construction flows. Moreover, the mentioned peculiarities of construction industry can be overcome with some solutions like standardisation, prefabrication etc., in order to take construction to the same level as manufacturing. (Koskela, 1993)

4.2.1. Continuous Improvement and Respect for People

As previously mentioned, continuous improvement is one the bases of Lean and together with respect for people are the pillars that support Lean in an organisation. Continuous improvement never ends, it is a philosophy where every solution implemented is a step for the next solution. Whereas the second concept means that the workers have to be empowered to make improvements and they have to be taught in order to grow and be able to solve problems by themselves. (Sacks, et al., 2018)

4.2.2. Waste in Construction

The waste in construction is one of the bases of Lean and refers to any activity or use of resources that does not provide value to the client. The client only pays for the things that are perceived as valuable. Therefore, any activity which does not add value is considered as non-value-adding work. In Lean philosophy, waste is strongly interconnected to continuous improvement and respect for people, explained in section 4.2.1. Respect for people provides many benefits that lead to an increase of value by using lower resources. Regarding continuous improvement, it is important for the organisation that the workers learn to see or identify the waste in order to continuously improve and eliminate waste accordingly. (Sacks, et al., 2018)

Traditional construction produces a huge amount of waste, this is due to the non-value-adding activities (Koskela, 1993). Table 4.3 shows the different types of waste in construction with its respective proportion.

Waste	Cost	Country
Quality costs (non-conformance)	12 % of total project costs	USA
External quality cost (during facility use)	4 % of total project costs	Sweden
Lack of constructability	6 - 10 % of total project cost	USA
Poor materials management	10 - 12 % of labor costs	USA
Excess consumption of materials on site	10 % on average	Sweden
Working time used for non-value adding activities on site	Appr. 2/3 of total time	USA
Lack of safety	6 % of total project costs	USA

Table 4.3 Waste in construction. (Koskela, 1993)

The waste in construction can be divided into following three. **Mura** is the waste of unevenness, unevenness causes a waste either by overusing the resources or lacking its utilisation. **Muri** is attributed to the waste of overburden. Either an overuse of the machines or the human resources can lead to a defects or problems in workers related to stress. Lastly, **Muda** is generated by the two previously mentioned types of waste, it is the intrinsic waste and is divided into the following seven types: (Sacks, et al., 2018)

- Transportation
- Inventory
- Motion
- Waiting
- Overproduction
- Over-processing
- Defects

Later, chapter 6, will explain all the uses of BIM and how BIM helps the general contractor to reduce the waste in construction.

4.2.3.Flows

Flow is defined by Koskela, as explained in section 4.2, as one of the three ways of thinking about production, together with transformation and value. It is also strongly connected with Lean construction as it is achieved by improving the flow. The process flow of a product in production corresponds to the different constructed spaces in construction, also called *location flow*. Whereas the *operations flow* is the required work on the product and corresponds to the flow of information, materials, equipment and trade crews. Lastly, the *portfolio flow* refers to the flow of projects in the portfolio of a company, seeing the project as a product where their resources can be allocated. (Sacks, et al., 2018)

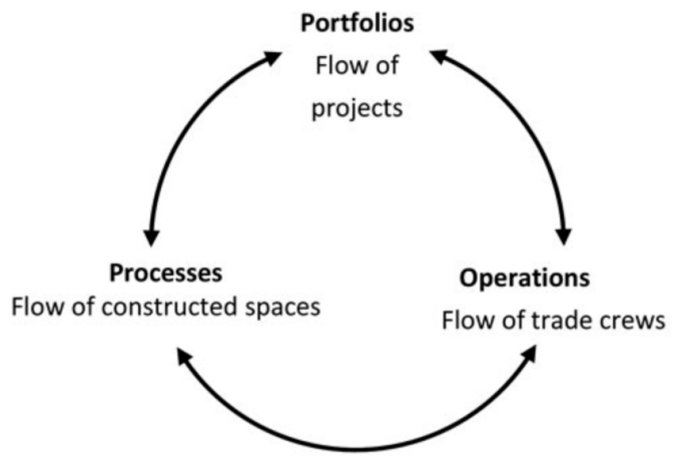

Figure 4.1 Loop of flows in construction. (Sacks, et al., 2018)

The flow is construction is different from the manufactured production because there are not products moving which makes it difficult to measure, control and identify bottlenecks. Another difference is that more than one crew can work in the same constructed space which generally reduces productivity. In construction, the sequence of the construction of the spaces is determined sometimes by technology. Structural construction has a logical order. However, finishing work do not have a determined sequence; therefore, some steps can be interchanged or done simultaneously. Batching in construction corresponds to when crews use large spaces to perform their work. Trade crews prefer it because they can work without conflicts with other crews, they can storage their materials there etc. Nevertheless, this does not benefit the project as a whole since it increases the cycle time and the Work in Progress (WIP). (Sacks, et al., 2018)

It is chosen to pay special attention to the process flow and operations flow because this thesis focuses on LPS, which is a method of planning and controlling a construction project. Process flow is managed by the work manager or site superintendent and consists of executing work to construct the spaces of the project. The manager uses production planning and control tools like LPS and location-based planning to ensure continuous work. Moreover, the manager seeks to reduce waste by reducing the WIP, minimising cycle time and maximising the quality. Operations flow is managed by the trade crew leader and consists of manging the trade crew. LPS can also be used for operations flow purpose beside other operational tools. The target of the crew leader is to achieve a good trade flow through the locations, having a productive, safety and continuous work. (Sacks, et al., 2018)

According to Sacks (2018), the conditions to have a good process flow and thus, a Lean construction are the following:

- Balanced work, no variability.
- The batch size must be one.
- No time buffer between trade operations.
- No re-entrant flow, which are the operations that has to be reworked.
- Reliable workflow, which can be achieve by the use of LPS.
- Number of trade crews is the same as the number of locations with WIP.

Whereas the conditions for a good operations flow are:

- Production stability
- Operation time reduced to minimum

In order to improve the process and operations flow, several Lean construction tools can be used. Among them, it has been chosen in the thesis to analyse the use of LPS together with the use of BIM-based tools that also contribute to improve the flow. (Sacks, et al., 2018) The ways that both tools help to improve the flow will be explained in the following chapters

LPS seeks to solve the problem of the hard achievement of good process flow and operations flow simultaneously, by solving the production variability, instability of supply chain and the individual interest of the participants. (Sacks, et al., 2018)

4.2.4. Production Planning and Control

Planning and scheduling embrace sequencing tasks in space and time, taking into consideration several constraints. For long time, bar charts were used to plan but they do not show how the tasks are linked. Instead, Critical Path Method (CPM) allows such linking but it only shows the duration of the tasks and it does not show the non-value-adding activities which means that is not valid for Lean construction. CPM is usually showed as a Gantt chart, an example is displayed in Figure 4.2 (Sacks, et al., 2018).

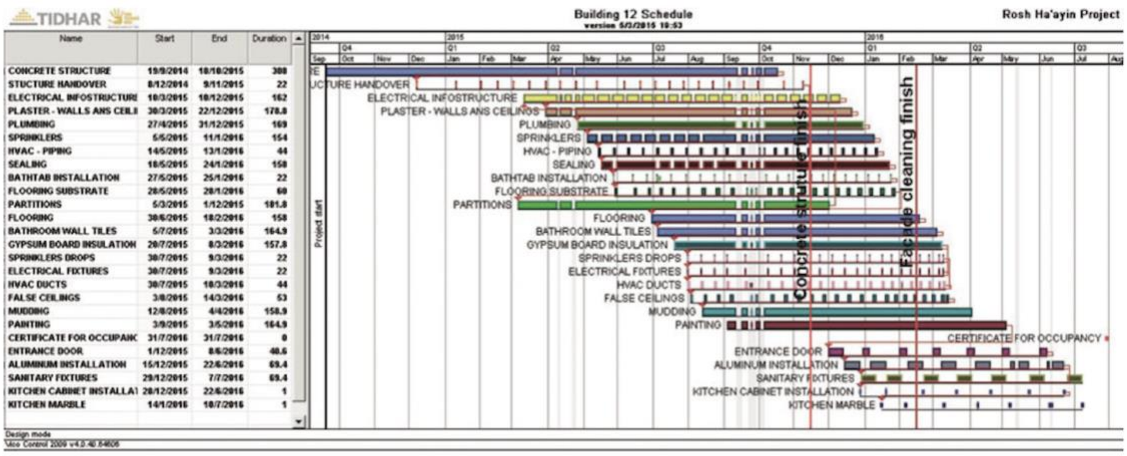

Figure 4.2 Gantt chart. (Sacks, et al., 2018)

Nevertheless, most of the building projects have the characteristics that the activities are repeated in sequences and are done by specialised crew. Therefore, location-based planning helps to have a continuous workflow by focusing on the movement of the crew (Kenley & Seppänen, 2010). Location-based planning breaks the project down in locations where the tasks take place. It is represented on Line-of-Balance charts (LoB), an example of LoB can be seen in Figure 6.5, page 34. As it was explained in the section 4.2.3, the products in construction correspond to the different locations. Therefore, this is where location-based planning has a huge advantage from CPM because it is able to model the product. LoB has the benefit of being easier to read that Gantt chart. It can be easy to identify waiting periods from empty areas of the schedule, discontinuous work from discontinuous lines of trades work or different work rates from different slopes of the tasks. As a control tool, can report a situation of conflict where two trades are located in the same place from two tasks crossing each other. Moreover, LoB supports the Lean principle of visual management since it provides valuable information about the project status in an easy and visual way to the different stakeholder. (Sacks, et al., 2018)

Regarding the power between the general contractor and the subcontractors in the traditional planning, the work managers command the subcontractors what work they have to do, without taking their constraints into consideration. In contrast, LPS, as a tool for Lean construction and later explained in chapter 5, allows every subcontractor to take part in the planning by providing the information of their constraints and agreeing to execute only the work they can do. (Sacks, et al., 2018)

Lean construction suggests keeping the batch size to the smallest possible. In construction, the products are the spaces; therefore, a crew has to be assigned to the minimum number of spaces in order to improve the flow and reduce waiting time and thus, cycle time. However, the fact of reducing the batch size can affect the chain in case of a problem in a task arises. Therefore, the batch has to be reduced in a controlled manner. Detailed planning reduces the amount of waste by minimising the amount of batch sizes. Moreover, it increases the ability of controlling and correcting. (Sacks, et al., 2018)

Continuous improvement is an important Lean principle, and in order to be effective, the processes of a contractor have to be standardised. A standard way of doing tasks, allows them to be measured and thus, improved. Sometimes the standardisation has no effect because of the local optimisation focus of the subcontractors. But when it can be implemented, it improves the production flow. (Sacks, et al., 2018)

5. Last Planner System

As a tool for applying Lean construction, and a step for implementing Lean by creating pull from the next upstream activity (Womack & Jones, 2003). *Last Planner System will be explained throughout this chapter with its phases, benefits and challenges.*

LPS is a production control and a short-term planning system started by Glenn Ballard at 1992. It is a mechanism that converts what **should** be done into what **can** be done, by checking the prerequisites and making an inventory of ready work. From these ready work, the Weekly Work Plans (WWP) are made. (Ballard, 2010)

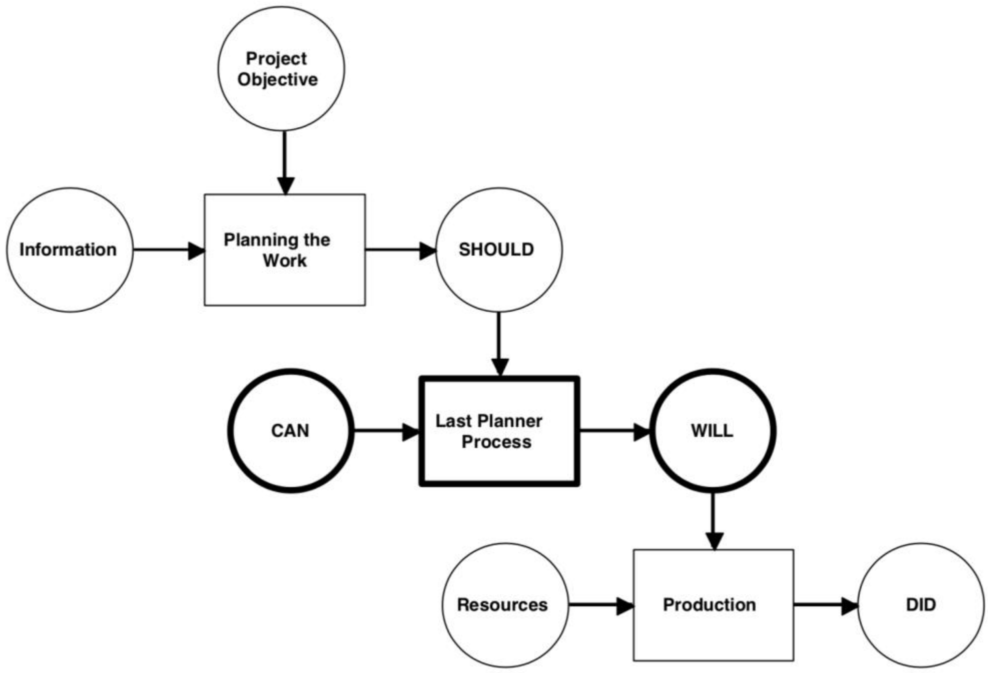

Figure 5.1 The Last Planner System. (Ballard, 2010)

5.1. Foundation

Lauri Koskela proposed five principles for a production control system in 1999. He also declares that they are applied in LPS. These five criteria are displayed below, and they create the foundation of LPS. (Ballard, 2010)

1. The assignment should be sound in order to start the work. Sound means that all the prerequisites of an assignment should be available.
2. The execution of the assignments has to be measured and monitored. It is measured by Percent Plan Complete (PPC), which it will be later explained.
3. The causes for when a task is not executed are inspected, and therefore, eliminated.
4. A buffer of sound tasks must be maintained in order to have workable backlog when some tasks are impossible to carry out. Then the crew can work on other tasks.
5. In lookahead planning (3-4 weeks ahead), the prerequisites of the planned activities are made ready in order for the assignments to be sound. This pull system will be explained later.

5.2. Push and Pull System

Push or the traditional system consists of pushing the tasks or the resources into the production process according the target delivery or completion dates. It is displayed in Figure 5.2.

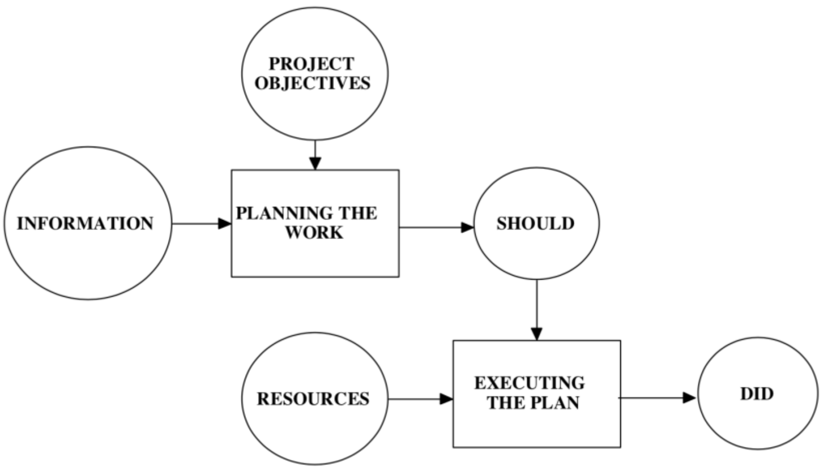

Figure 5.2 Push system. (Ballard, 2010)

On the other hand, pull system is a method that consists of pulling the tasks, the resources or the information to the production process whenever they are needed to carry the work out. LPS is based on the pull system because of the lookahead plan, that will be later explained. The assignments are made ready in order to be pulled with the resources when they are needed. The pull system is shown below in Figure 5.3.

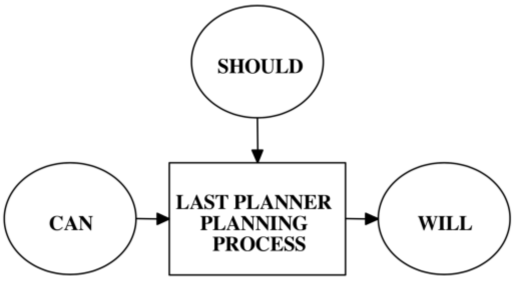

Figure 5.3 Pull system. (Ballard, 2010)

5.3. Planning Levels

Figure 5.4 shows an overview of the planning system of LPS. It contains the different planning levels which will be explained individually.

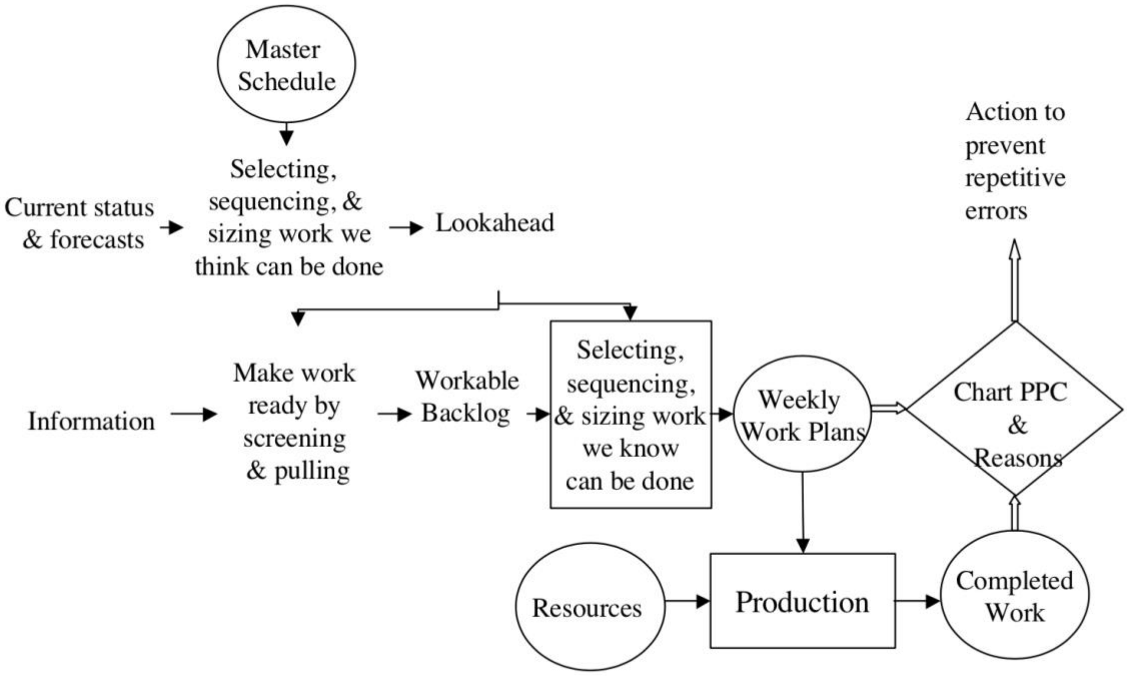

Figure 5.4 Planning system of LPS. (Ballard, 2010)

5.3.1.Master Schedule

It is a plan where the agreement between the client and the contractor is stablished regarding what it should be done in the construction process. It is used to determine the overall budget and the general schedule. It is made as a Gantt chart where the most important information is the handover date.

The Master Schedule contains the milestones which divide the project and they show what has to be done at that assigned deadline. Therefore, it shows the sequences of time where the activities should be carried out.

5.3.2.Phase Schedule

Because of the complexity of construction projects, a more detailed schedule is needed to avoid problems as a result of the lack of details. Therefore, this schedule will set the phases for the future lookahead plan that will be explained in the following.

The Phase schedule is the result of the agreement between the contractor and the subcontractors. Therefore, the involved parties negotiate in a collaborative programming how the building process will be like, with its respective order and time spent within the frames of the Master schedule. Last Planner System tries to achieve the agreed goals which were set during the collaborative programming.

The collaborative program makes the schedule by pulling it backwards and identifying the constraints. It is recommended to use a big board and using post-it papers with different colours for the different trades and milestones.

According to Sven Bertelsen, the uses of a collaborative program are:

- Work plan
- Organisation chart
- Agreement between trades
- Logistics plan
- Tool to control the workflow
- Basis for monitoring progress (Mossman, 2013)

5.3.3.Lookahead Plan

As it is shown in the Figure 5.5, lookahead planning is the process in which the activities from the Master and specially Phase Schedule are taken as a work packages and entered in the lookahead window for at least six weeks. The activities that are not possible to remove their constraints will not be added to de lookahead window. Then it is turn of the screening and pulling, where each activity will be analysed against its constraints and try to remove them. Depending of the assignment there might be different constraints:

- Design
- Materials
- Prerequisite work
- Space
- Equipment
- Workers
- External conditions

The sound activities from the lookahead window are introduced in the workable backlog which are activities that can be executed because all their constraints have been removed. This process is shown below I n Figure 5.5. (Ballard, 2010)

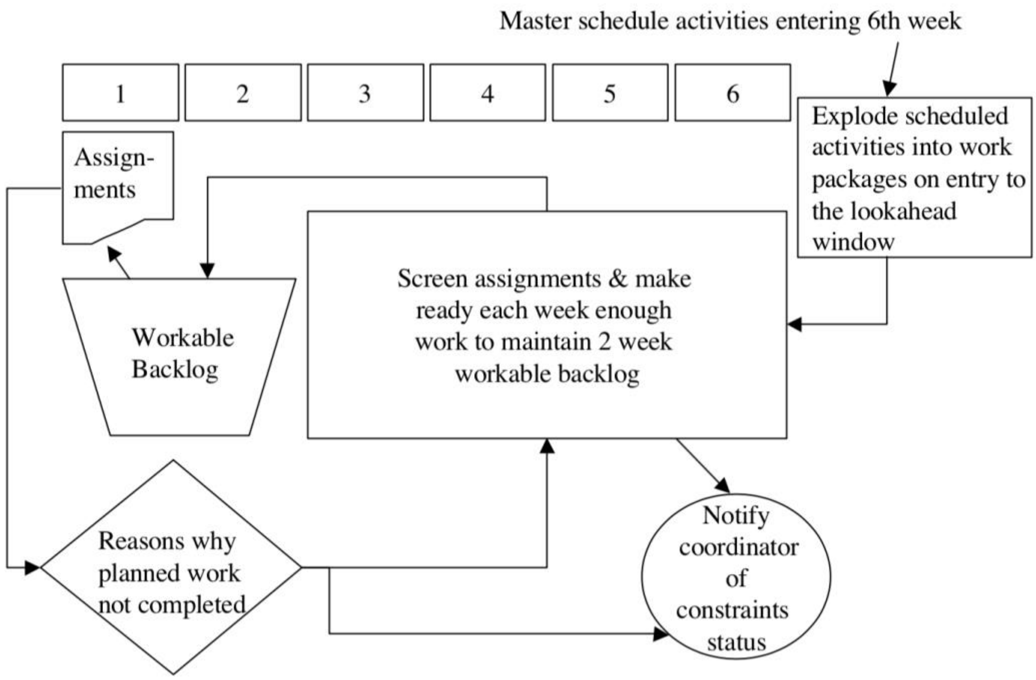

Figure 5.5 Lookahead process. (Ballard, 2010)

5.3.4. Weekly Work Plan

Weekly Work Plans (WWP) are made from the workable backlog by the “Last Planner”. Therefore, the plan contains sound activities that **will** be performed during the following week.

5.4. Measurement and Continuous Improvement

According to Ballard (2010), the key performance indicator of a planning system is the output quality. In order to measure it, LPS uses the Percent Plan Complete which is the percentage of the planned activities completed over the total planned activities. PPC measures to what extent the **will** was executed.

$$PPC = \frac{\text{Planned activities completed}}{\text{Planned activities}} \cdot 100\%$$

Afterwards, the planned activities that were not carried out are analysed in order to identify the reasons of not completion to learn and improve the PPC and the project performance in the future. Tools for such analysis can be cause-effect diagram or 5 Why.

Regarding the reason for the not completion of the sound activities, can be found:

- Failure on removing the constraint
- Failure to apply quality criteria
- Failure in coordination of shared resources
- Change in priority
- Design error (Ballard, 2010)

5.5. LPS Benefits

In a study made by Fernandez-Solis, et al. (2013), the benefits of LPS were reported according to what was experienced in 26 case studies. These benefits will be listed in Figure 5.6. The figure also shows the number of cases that the benefit had impact on.

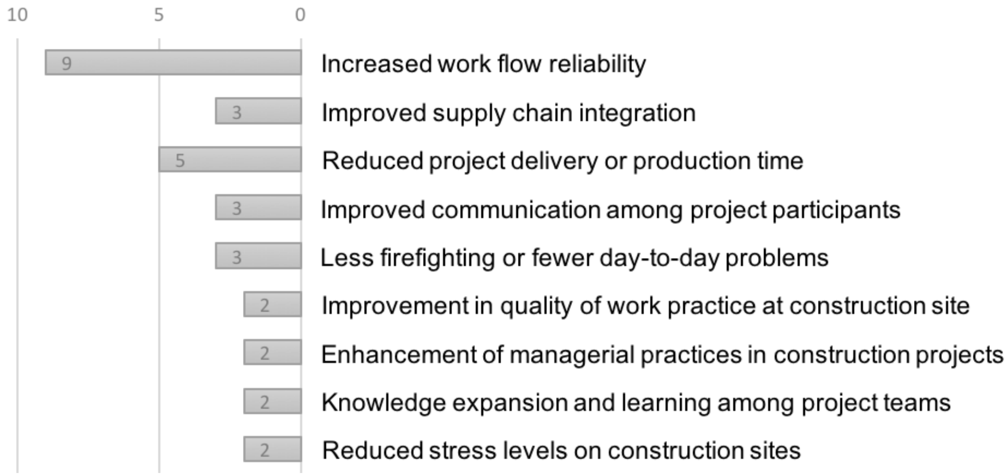

Figure 5.6 LPS benefits. (Amended from (Fernandez-Solis, et al., 2013))

It is clearly visible that LPS has as its most repeated benefit the increase of workflow reliability, whereas the second is the reduce of production time.

Another important benefit to be added to the ones already listed would be that LPS focuses on the global interest of the project team, instead of the individual interest of a trade for instance. (Sacks, et al., 2018)

5.6. LPS Challenges

Regarding the challenges, the same study made by Fernandez-Solis, et al. (2013) also shows the challenges collected from literature and how often they were repeated in the selected 26 case studies. It is displayed below in Figure 5.7.

The challenges most found in the case studies were firstly the conservative philosophy of the organisation. Secondly, the lack of training, skills and experience. And thirdly, the negativity regarding LPS together with the lack of engagement.

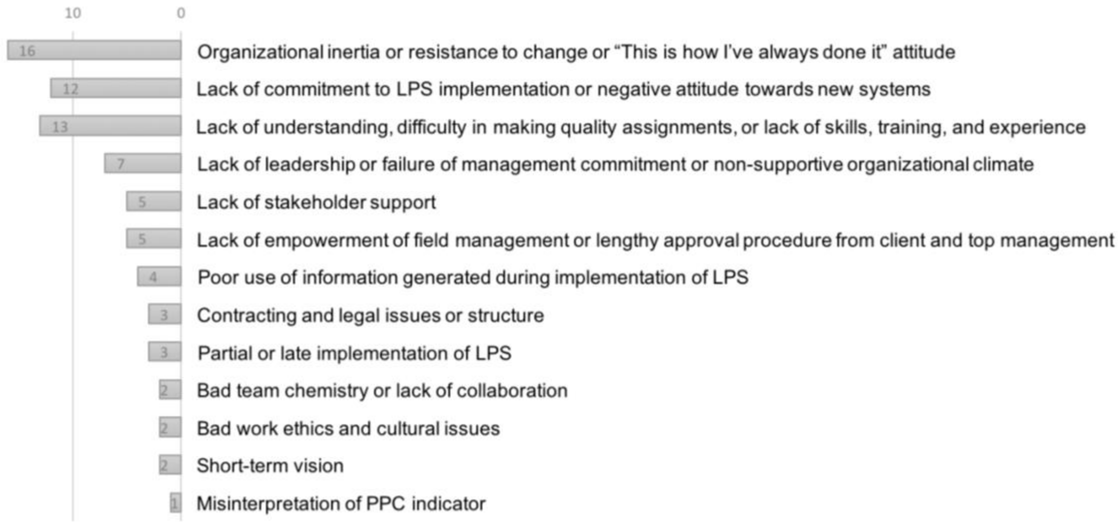

Figure 5.7 LPS challenges. (Amended from (Fernandez-Solis, et al., 2013))

5.7. LPS Application in Design

This report will only focus on LPS during the construction phase. However, LPS can also be applied in the design phase. Several studies have confirmed its applicability and benefits during the design phase. Moreover, it increases completion rate of the tasks in design. The design team also become proactive. The lack of reliable promises triggers inefficiency in all phases of a project. (Fosse & Ballard, 2016)

6. Building Information Modelling

This chapter will explain what BIM consists of and its characteristics. Moreover, it will present the different uses that has within all the life cycle. The functionalities that has during the construction phase will also be explained in detail. Lastly, the chapter will be ended with its benefits and challenges.

6.1. Drawing-based Information

Through a great amount of investigations, it was determined that the main problem of the under performance of the construction industry was the poor standards of information management. Most of the information in the AEC industry starts from the designing drawings which has poor information. These causes two unavoidable problems in drawing-based information. Firstly, the information is unreliable; therefore, the receiver has to check and ensure that it is correct which takes time and requires skills. Secondly, drawing-based information is un-computable, the receiver has to decode it and then introduce it a new system which can cause several errors. (Crotty, 2012)

In contrast, BIM promotes to improve the quality of design information and the way it is shared among the project team. In consequence, it adds value and it helps to remove the waste during the design and construction (Sacks, et al., 2018). Figure 6.1 displays the different levels of sophistication of BIM use, starting from manual drafting, till the collaborative BIM with an integrated model.

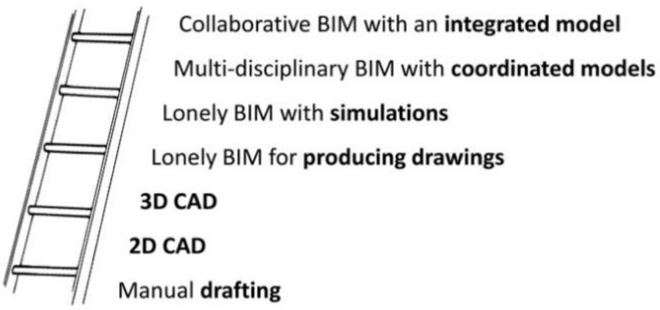

Figure 6.1 Levels of BIM use. (Sacks, et al., 2018)

6.2. What Is BIM?

According to Arayici (2015), *"BIM is defined as the use of Information and Communication Technologies to optimise the building lifecycle processes in order to provide a safer and more productive environment for its occupants, to affect the least possible environmental impact from its existence, and to be more operationally efficient for its owners throughout the building lifecycle."*

BIM contains digital description of the building elements and the relationship between each other for several purposes of the stakeholders. Moreover, it integrates the processes during the lifecycle of a project. Lastly, BIM supports Virtual Design and Construction (VDC), which will be explained in section 6.3. It requires collaboration, such as using IPD, previously explained in section 3.4. Figure 6.1 also explains the importance of the collaboration as being represented as the highest sophistication level. Furthermore, BIM also supports the interoperability which will be explained below. (Eastman, et al., 2011)

Interoperability

According to Eastman, et al. (2011), *"Interoperability is the ability to exchange data between applications to smooth workflows and sometimes facilitates their automation."*

Unfortunately, the different stakeholders use BIM with different BIM applications during most of the life cycle. However, the models have to be exported and imported fluidly between them. (Arayici, 2015) Hence, several exchange formats are available for such purpose. If the interoperability is missing, it can affect the workflow, inducing project delays, conflicts and errors. (Forbes & Ahmed, 2010)

6.3. Virtual Design and Construction (VDC)

Several contractors have benefitted from using BIM and Lean practices as two separate initiatives. However, it is sub-optimal to implement efficient technology into inefficient processes or vice versa. Therefore, VDC has emerged as the solution of this problem. Virtual Design and Construction is a term coined by the Center for Integrated Facility Engineering (CIFE), which is a framework that focuses on using BIM and Lean practices. (Fosse, et al., 2017)

According to Sacks, et al. (2018), VDC entails the following steps, also illustrated in Figure 6.2. The six steps are divided in three phases; virtual design, virtual construction and construction.

1. Generation of the design model using BIM tools.
2. Simulation of the building model using a software.
3. Planning the construction process using BIM tools to generate a digital construction model.
4. Simulation and analysis of the digital construction plan using software.
5. Construction of the building according to the model, including monitoring and recording of the construction process.
6. Recording of the as-built state by updating the digital model.

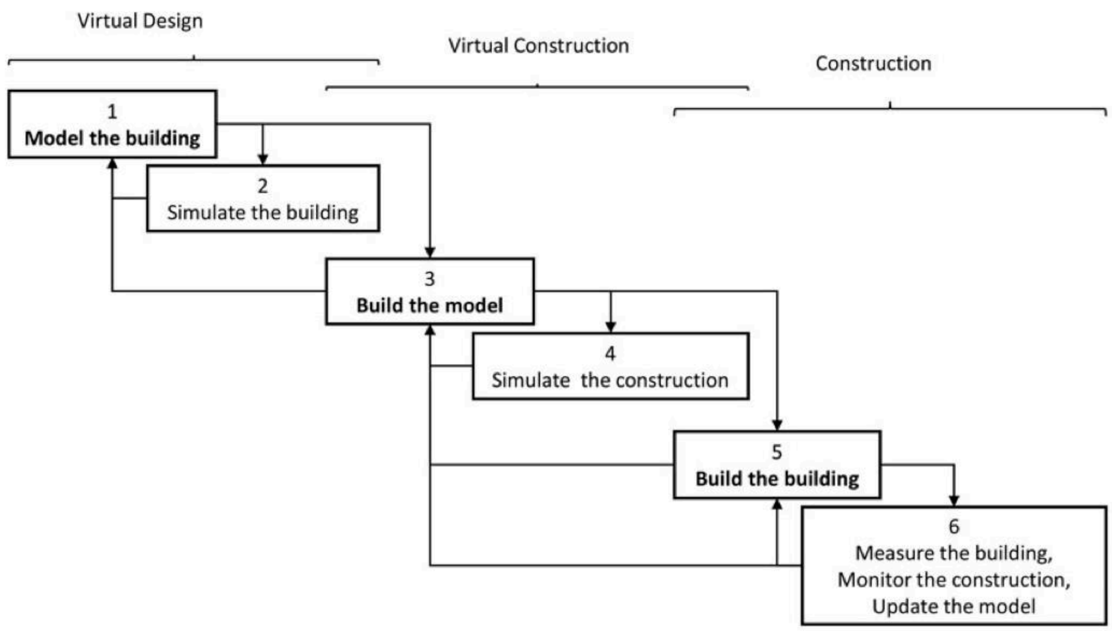

Figure 6.2 Steps of VDC. (Sacks, et al., 2018)

6.4. Uses of BIM

The use of BIM is made during the whole building lifecycle. As it is shown in Figure 6.3, the use of BIM is included in the planning, design, construction and operational phase. These uses will be explained below.

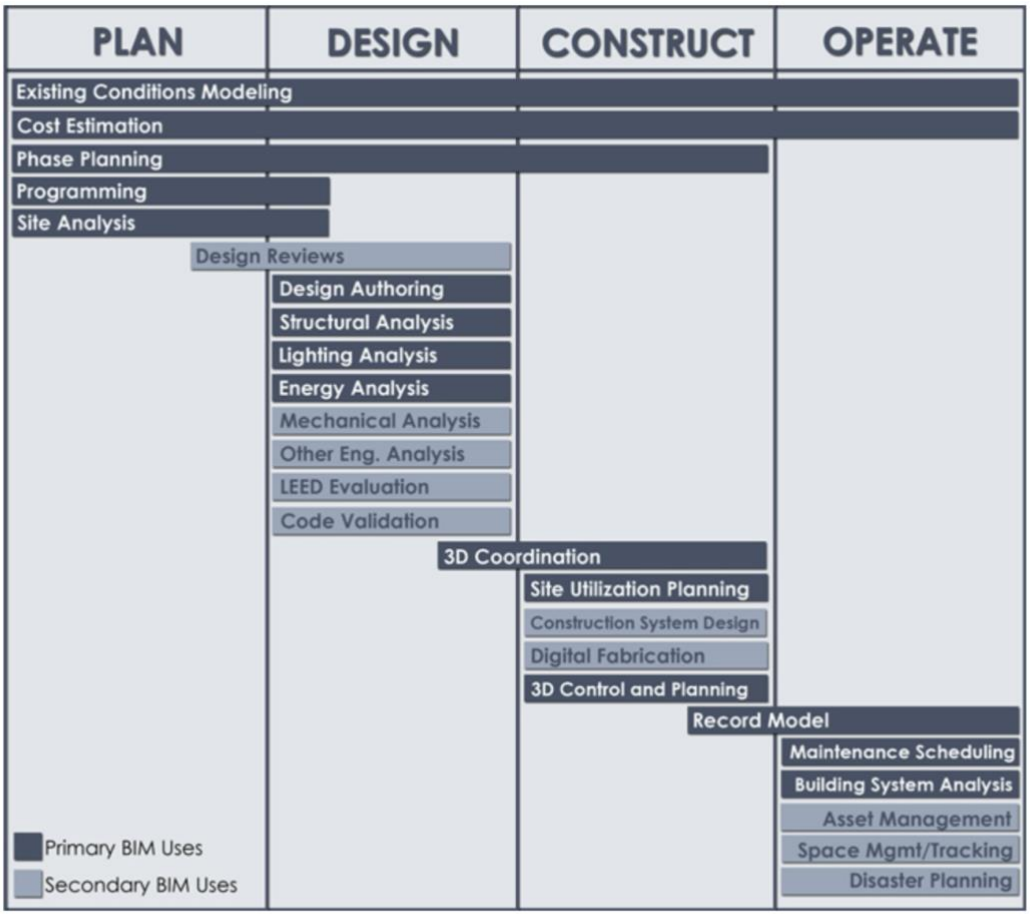

Figure 6.3 BIM uses during the lifecycle. (Arayici, 2015)

Planning Phase

BIM can integrate in a BIM model all the information gathered by the architect regarding planning, feasibility studies, as-built information, topography etc. The information that might affect the size and orientation of the building. Through this model, a conceptual design can be elaborated with its respective quick cost estimation. (Arayici, 2015)

Design Phase

During this phase, the designer has to focus on his client's budget and requirements and make a harmony between the constraints; scope, schedule and cost.

With the use of BIM in the design phase, the architect and the project team can work in a collaborative way, being able to design more accurately, rapidly and effectively. From a single source, BIM integrates the design documents, schedules, quantities and other information. (Arayici, 2015)

Construction Phase

From the previously mentioned single source characteristic of BIM, the construction team is able to get the scheduling and cost information of the project in the construction phase. This information is got from the synchronised and accurate BIM model from the design team. It decreases the time and increases the effectiveness of the construction execution. The contractor can communicate about logistics or the utilisation of the building site. (Arayici, 2015) The different uses of BIM in the construction industry will be deeply explained below in section 6.5.

Operational Phase

During this phase, BIM helps facility managers by giving the physical information such as furniture and equipment, finishes, rental income, leasable areas; and information regarding the necessary performance and operational processes for the management of the facility. (Arayici, 2015)

6.5. BIM in Construction Industry

The use of BIM in construction provides a smoother workflow which reduces the time and the money. Moreover, it cuts down the amount of conflicts and errors. (Eastman, et al., 2011) This section will explain how a contractor can achieve these benefits.

6.5.1. Clash Detection

For a long period, the clash detection was carried out manually by using 2D drawing on a lighted table. Contractor could also make this manual conflict detection by CAD layers. Regarding the traditional 3D clash detection, the clashes were only geometric clashes without meaning. (Eastman, et al., 2011)

Fortunately, the time has changed, BIM-based clash detection tools can automatically execute the clash analysis geometrically and parametrically and between different systems like mechanical and structural. Soft clashes can easily be found because it can be set to search for limited clearance between different elements. It is a requirement that the models have to be in a great level of detail by any of the project team for the clashes to be accurately detected. (Eastman, et al., 2011)

Two clash detection types can be defined. One is the clash detection with BIM design tools, it is used during the design phase. Whereas clash detection with BIM integration tools is used by the contractor integrating the different file formats from different designers. These tools are more specialised and provide a deeper analysis of hard and soft clashes. Solibri Model Checker is an example of such tools. (Eastman, et al., 2011)

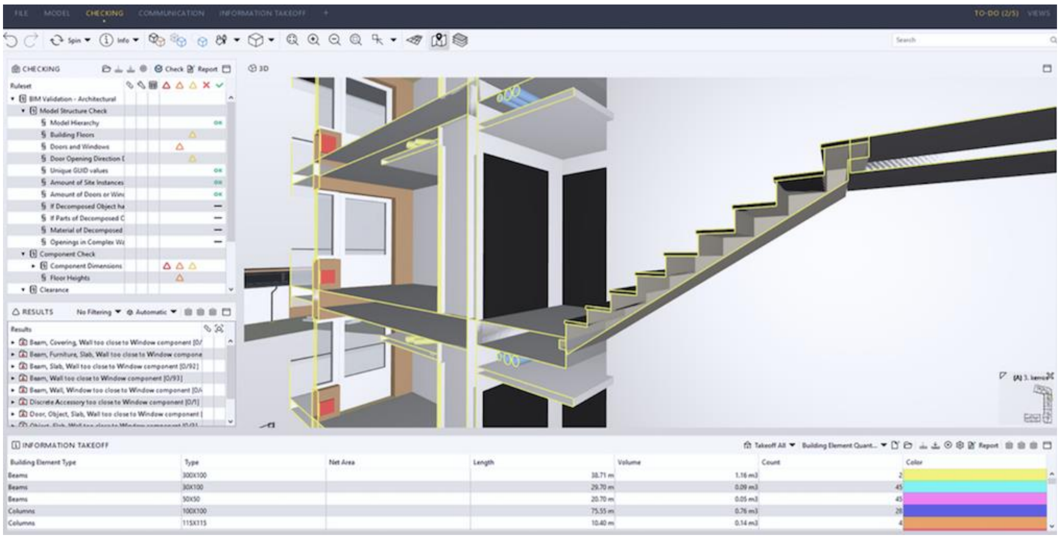

Figure 6.4 Clash detection in Solibri Model Checker. (Solibri)

6.5.2.Quantity Takeoff and Cost Estimating

Regarding cost estimations, they can be either made at an early stage of the design in order to have design alternatives if it is over budget, or they can also be more accurate once the design is finished. The advantage of using BIM from the early design is that the quantity takeoff is parametric. Therefore, several types of quantities like number of floors, lengths, spaces etc., can be extracted. (Eastman, et al., 2011)

All BIM tools can provide quantity takeoff for approximate cost estimation. However, contractors require more accurate ones, but it might exist problems regarding how detailed the building components are. Therefore, that is why contractor and subcontractors must be added at an early design phase. It has to be stated that BIM tools provide an accurate quantities takeoff which facilitates the estimators to produce the cost estimations. BIM does not automatically produce estimations because it does not asses several risk conditions. In conclusion, BIM only removes the uncertainty of materials quantities. The estimation can be made by three methods which are the following. (Eastman, et al., 2011)

1. Export quantities from BIM tools to estimating software, like for example MS Excel which was the most commonly used for cost estimation (Sawyer & Grogan, 2002).
2. Link BIM components to Estimating software, like Vico Estimator which allows the linking of the BIM elements to an estimating package or an external cost database.
3. Quantity takeoff tool, such as Vico Takeoff Manager which imports the data from the BIM tools. The benefit is that the contractors only use this tool designed for their needs, they do not need to learn other BIM tools.

6.5.3. Construction Analysis and Planning

As previously explained in section 4.2.4, the traditional methods do not link the tasks with location. Moreover, the scheduling is not linked to the model and it becomes a manual task. Lastly, with the Gantt chart is hard to evaluate within the stakeholders. For this reason, three types of technology have evolved. (Eastman, et al., 2011)

1. 4D CAD, which are 3D models with time association.
2. Use of analysis tools that incorporate BIM components and construction information.
3. Use of Last Planner System (LPS), explained in chapter 5. LPS can be supported by BIM in several manners, like visualisation of the construction process

4D Models

According to Eastman, et al. (2011), *"BIM allows the schedulers to create, review and edit 4D models more frequently, which has led to the implementation of better and more reliable schedules."* The construction plan can be simulated and share it with the project team by using 4D CAD. The elements of the model have to be assigned to the phases of the construction and linked to its required activities, also temporary structures in case are needed. This is why the contractor has to be added at early design stage, the contractor can provide constructability, sequencing and cost estimating knowledge. The benefits of 4D models are the following. (Eastman, et al., 2011)

1. Communication of the planned construction to all project stakeholders.
2. Multiple stakeholder input.
3. Site logistics.

4. Coordination among trades.
5. Track of construction progress.

The 4D modelling process could be made in three ways; manually using 3D or 2D tool, creating 4D features in a 3D tool or lastly, exporting 3D to 4D tool and importing schedule. Vico Office tool allows the importation of a 3D model and the later scheduling as location-based, it also provides some other features like, quantity takeoff, cost estimation etc. (Eastman, et al., 2011)

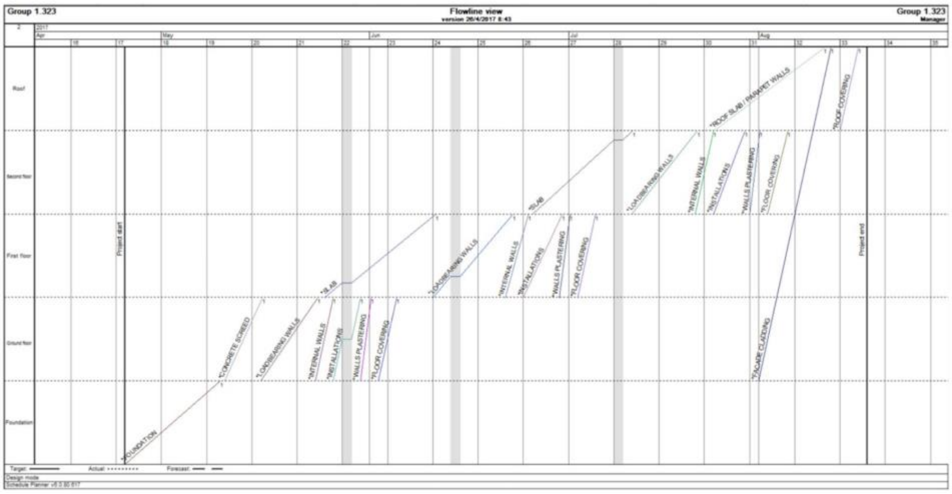

Figure 6.5 Location-based schedule from Vico Office.

6.5.4. Cost and Schedule Control and Management

BIM provides valuable help to have control and management of the project status because its detailed quantity and information can be linked to other tools. The uses for such purposed are the following. (Eastman, et al., 2011)

1. **Actual cost tracking**, Vico Office allows the import of actual costs in order to check the variance with the budget using the 3D model.
2. **Project status**, bottlenecks can be identified by previously defining the status of each of the components. It can be associated with colours for easier identification.
3. **Procurement**, BIM provides the option to directly purchase what is defined as needed.
4. **Procurement tracking**, planners are able to identify problem in the procurement by checking the status of the activities. In 4D, it is possible to visualise how the delay affects the construction process.

5. **Safety management**, by using a 4D model, unsafe areas and conflicts can be detected and solved in advance.

6.5.5. Offsite Fabrication

Assuming the benefits of the offsite fabrication, BIM allows the contractor to introduce to the BIM components details, geometry, specification, finishing, delivery time etc. It is valuable for the project that the contractor has an early coordination with the subcontractors in order to reduce time and errors by exchanging information.

6.5.6. Onsite Use

In the building site, BIM can be used for verification, guidance and tracking of the construction tasks. The contractor has to verify the construction in order to check if it is according the model and the specifications are met. In case some errors are found, the contractor must rectify them. (Eastman, et al., 2011) Catching possible error in advance is critical for quality control. 6-12% of construction cost comes from repairing late detected errors. (Josephson & Hammarlund, 1999) Some of the available automated technologies are the following.

1. **Laser scanning technologies** are able to measure and export the data to a BIM tool to check if the component is well located. However, it cannot be used in tight areas and it does not provide real-time quality assessment. (Dong, et al., 2009) Navon (2005) demonstrated that by a real-time quality control system the manager can provide better decisions.
2. **Machine guidance technology** using dimensions extracted from BIM model.
3. **GPS technology** linked to the model to verify locations.
4. **Radio Frequency Identification (RFID)** for tracking delivery and installation.

6.6. BIM Benefits

Planning Phase

1. **Concept, feasibility and design benefits**, a building model linked to a cost database can be helpful to determine if a building is feasible for the owner.

2. **Increased building performance and quality**, it is caused by an early evaluation of performance and quality among several design alternatives
3. **Better collaboration** using Integrated Project Delivery (IPD), it helps the project team to understand the project requirements and the cost estimation. (Eastman, et al., 2011)

Design Phase

1. **Direct design visualisation**, through the 3D model view which is directly generated at any stage.
2. **Automatic corrections**, through the parametric characteristic of BIM.
3. **Accurate 2D drawings**, 2D drawing can be extracted from the model.
4. **Early collaboration** of the different designers through a coordinated 3D model
5. **Easy consistency verification**, in the building model, quantities can be taken-off to check if the requirements of the client or the function of the building are being met.
6. **Quantity take-off** during the Design Phase in order to get the cost estimation to keep the parties aware.
7. **Better energy efficiency and sustainability** because of the tools for energy analysis at early stage. (Eastman, et al., 2011)

Construction Phase

1. Use of the 3D design model as a **basis for the fabrication of components**; steel, glass fabrication etc. It reduces the cost and time of prefabrication.
2. **Quick reaction of any design changes**, since the design model will be updated.
3. **Early error detection**, hard and soft clashes are detected in advance. Therefore, through the coordination among the parties, the errors can be omitted.
4. **Simulation of the construction planning**, this provides an insight into how the building will be constructed, and how it will look lime at any time. This reveals possible conflicts. In addition, temporary construction objects can also be linked to help to plan.
5. **Better Lean implementation;** BIM allows a better coordination between the contractor and the subcontractors and that is what Lean requires in order to know when the work can be performed and when the resources will be available.

6. **Use for procurement,** the quantities, specification, or properties of the materials or objects contained in the model can be used to procure from suppliers or subcontractors. (Eastman, et al., 2011)

Operational Phase

1. **Better commissioning** and handover of facility information, during the construction phase, MEP contractors link information of the installations and the maintenance to the building model.
2. **Improved facility management**, since all the information for the systems used in the building is included in the building model. (Eastman, et al., 2011)

6.7. BIM Challenges

According to Arayici (2015), BIM has some side effects for the AEC industry besides all the multiple advantages. These negative impacts are described below.

1. **Economic cost** of BIM, the cost of moving from traditional approach to BIM is contemplates as considerable. In this part it is included both the software and the hardware. Moreover, the training of the staff has also a substantial impact on the cost.
2. **Interoperability**, an other crucial challenge is regarding the translation of the BIM models. BuildingSmart set the Industry Foundation Class (IFC) which is an universal BIM format for most of the programs, however during the data exchange it exists some data loss. This is because the tools used are from different vendors.
3. **Process change**, the construction knowledge has to be introduced at an early stage of the design process. Therefore, the companies will have to adapt to have a shared model during design and construction which requires time and education. Companies capable of design-build which can coordinate the construction knowledge will benefit the most from BIM. (Eastman, et al., 2011)
4. **Legal changes**, in terms of who is the owner of the data regarding, design, fabrication, analysis and construction. Moreover, who is liable for the inaccuracies.

7. Interaction of BIM and Lean

This chapter will contain an analysis of the interactions of BIM and Lean found by Sacks, et al. (2010).

7.1. Interaction of BIM and Lean During All Phases

Lean can be implemented without any technology. However, technological support, BIM in this case, can support its implementation. (Sacks, et al., 2018)

According to Eastman et al., (2011), there are solid synergies between BIM and Lean construction, this means that the use of BIM leads to the accomplishment of the Lean principles in construction. Information is probably the hardest flow to coordinate, measure and control in construction (Sacks, et al., 2018). As mentioned in section 6.1, one of the biggest problems that causes waste in construction is regarding the poor information contained in drawings and its management and communication. But besides the information in the models, it is also included the process information which contains flow of work, flow of materials, crews etc. BIM helps solve all these problems; moreover, it also enhances the workflow during the construction phase for the different parties. (Sacks, et al., 2018)

Sacks, et al. (2010) elaborated a study where they compared 24 principles of Lean with 18 functionalities of BIM, providing the interactions between them. The result consisted of having 52 positive interactions among 56 total interactions. Figure 7.1 and Figure 7.2 show the amount of interactions that the Lean principles and BIM funtionalities have respectively.

Figure 7.1 Amount of interactions of Lean principles. (Amended from (Sacks, et al., 2010))

As it is visible in Figure 7.1, the Lean principles that interact more often with BIM are the ones regarding variability reduction (A and B) and production cycle time reduction (C). Variability reduction refers to getting the quality of the product right at the first time and focusing of improving upstream flow variability. These mentioned interacted principles are not only delimited to the designing functionalities of BIM, they are also interacted in the construction. (Sacks, et al., 2010)

In regard to BIM functionalities, Figure 7.2 shows the ones most interacted with Lean principles. These are the aesthetic and functional evaluation (1), multiuser viewing of the multidiscipline model (10), 4D visualisation of construction schedules (13), visualisation of process status (14) and lastly, online communication of product and process information (15). The functionalities located from 1 to 8 belong to design, from 9 to 10 are in design and fabrication, whereas the rest correspond to preconstruction and construction. Besides the fact that BIM was primarily distinguished as a tool for designing, one can appreciate in this chart that most of the mentioned functionalities (10, 13, 14 and 15) belong to fabrication and construction management functions of BIM. (Sacks, et al., 2010)

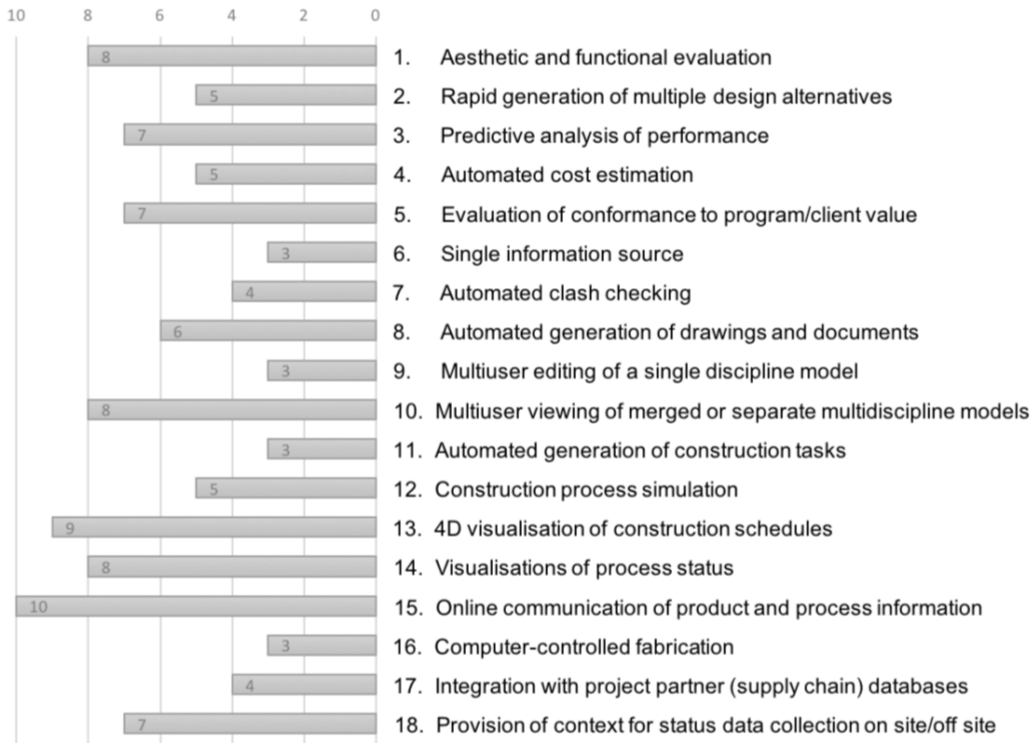

Figure 7.2 Amount of interactions of BIM functionalities. (Amended from (Sacks, et al., 2010))

Some studies have demonstrated that the use of IT technologies can have a positive impact in the design but not in construction management (Howard, et al., 1998), cost might be greater than benefits (Gann, 2000) and the existance of hard barriers regarding cost and great know-how required (Rivard, 2000). However, Sacks, et al. (2010) stated that for achieving the benefits of BIM, the changes of information and material processes must be based in process changes, BIM tools and Lean construction principles. Lastly, the sinergies between Lean and BIM have to be seen globally and not like an addition of individual interactions, because each principle or functionality has multiple interactions among them. (Sacks, et al., 2010)

PART III. SOLUTION

8. Interaction of BIM and Lean Construction

This chapter will concern, as the previous chapter, the interaction of BIM and Lean but during the construction phase. It will explain how the BIM functionalities interact with the Lean principles. Furthermore, two construction management systems that use BIM and Lean principles will also be presented.

Considering this thesis focuses on LPS as a tool for applying Lean construction, it has been chosen to select the Lean principles that correspond to the analysis, planning and control of the construction using LPS. The Lean principles are taken from Figure 7.1 and the BIM functionalities that interact with them from Figure 7.2, which are regarding preconstruction and construction. This is made to develop the interaction matrix of BIM and Lean in the construction phase with the help of the study made by Sacks, et al. (2010). The several interactions will be numbered as the ones in the study for an easier recognition. The Lean principles and BIM functionalities will be displayed in the matrix Table 8.1 Afterwards, the several interactions will be explained through each BIM functionality.

Lean principles / BIM functionalities	**A** Get quality right the first time (reduce product variability)	**B** Improving upstream flow variability (reduce production variability)	**C** Reduce production cycle durations	**D** Reduce inventory	**E** Reduce batch sizes	**H** Use pull systems	**I** Level the production	**K** Institute continuous improving	**L** Visualise production methods	**M** Visualise production process	**U** Verify and validate	**V** Go and see for yourself	**W** Decide by consensus, consider all options	**X** Cultivate an extended network of partners
7 Automated clash checking	12	12	22								12			
11 Automated generation of construction tasks	14		25											
12 Construction process simulation		15	25				37				47			
13 4D visualisation of construction schedules	2	40	25						40	40	47		49	
14 Visualisations of process status		29	26	30	30	34				34	47	48		
15 Online communication of product and process information	18		26	30	30	34			38	34			49	
16 Computer-controlled fabrication	19		27											
17 Integration with project partner (supply chain) databases		20	28			35								50
18 Provision of context for status data collection on site/off site		21		30	30	34		39			47	48		

Table 8.1 Interactions of BIM and Lean in construction. (Amended from (Sacks, et al., 2010))

Automated clash checking

Using a BIM software that integrates the several models, merges them, check automatically the clashes and solves them; reduces the product and production variability by eliminating the errors on site and it also reduces the cycle time. Moreover, it can be used to verify and validate. Bhatla & Leite (2012) included the clash detection in their Integration Framework of BIM with the LPS to enhance workflow reliability during the construction phase.

Automated generation of construction tasks

BIM allows the automated generation of the construction tasks which reduces the product variability by avoiding human errors and skipping tasks when planning. It also reduces the cycle time of the construction because of the optimisation of the schedules and having less conflicts.

Construction process simulation

The simulation of the construction process decreases the production variability by having a discrete event simulation which improve production processes. Cycle time of the construction is reduced by optimising the schedules. Discrete even simulation can also level the production by assessing the work and evening the work allocations. Together with the visualisation of the current processes helps to verify and validating process information.

4D visualisation of construction schedules

The visualisation of the construction schedules reduces the product variability by being easier to catch mistakes or incomplete parts. BIM is able to simulate the methods with temporary equipment, also the visualisation of the processes which helps to avoid conflicts in time and space during the construction. Therefore, it improves the production variability. It also reduces the cycle time of construction by optimising the schedules. With the visualisation of the current processes, it supports the verification and validation of the process information. Lastly, visualising the construction schedules makes possible a participatory decision making because it provides better information to the participants.

Visualisation of the process status

It reduces the production variability by being able to choose several solutions from a wider design inventory in the last responsible moment. The visualisation of the process status also reduces the cycle time since the activities can be executed after each other with small delay between them. It can help to manage the production to reduce inventories and batch sizes. The visualisation also allows the team to choose the best work allocation for ensuring a continuous workflow by using pull system. It helps to verify process information. Finally, it allows the manager to follow the process up without having to check on site, even though it is not the same.

Online communication of product and process information

It helps to reduce the product variability since it might identify conflicts when the product information is updated. It also reduces the cycle time by executing tasks with little delay. It gives the possibility to communicate and therefore reduce inventories and batch sizes. It allows the team members to allocate the work for continuous workflow using the pulling system. Workers can access online to the standards of the production to visualise the production methods. Online communication facilitates the decision making by providing the information to the people involved.

Computer-controlled fabrication

It transfers automatically the data of the products for fabrication, avoiding the manual labour and the human mistakes. Therefore, it reduces the product variability and the cycle time.

Integration with project partner (supply chain) databases

The integration of project partners allows the direct information for ordering or renewing material deliveries which produce a decrease of the production cycle duration and the production variability. It also strongly helps to use pulling system in terms of delivering material or design information. Lastly, it supports the Lean principle of creating and improving the relationship with the project partners.

As it is displayed in Figure 8.1, the use of BIM allows the pull flow Kanban from construction to obtain the detailed design information whenever is required. This contributes to Lean construction since it reduces cycle times and implements pull system as already stated.

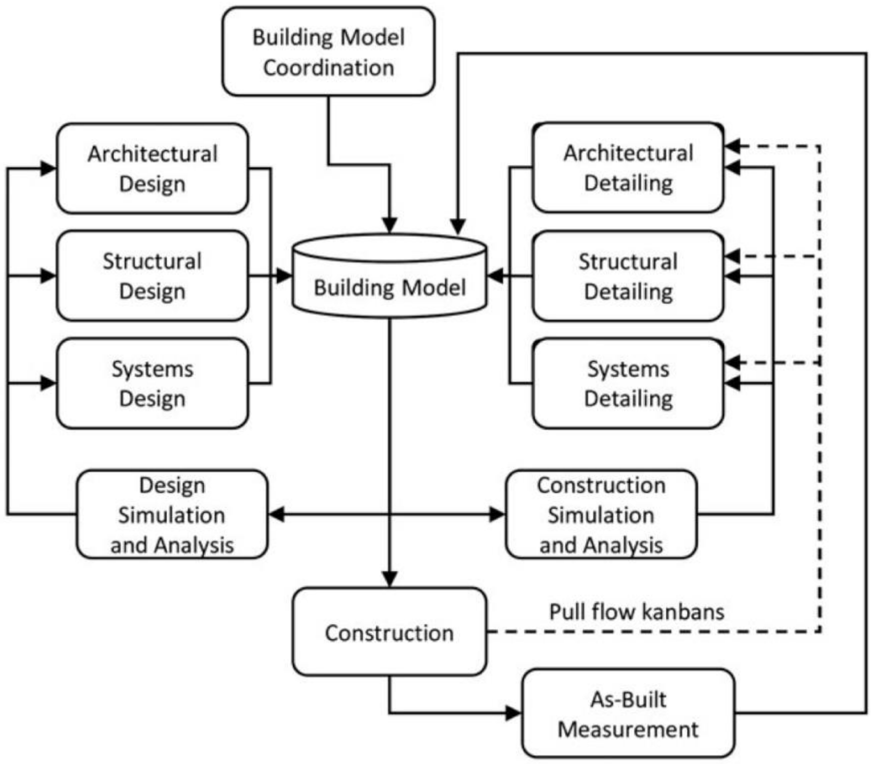

Figure 8.1 Lean application in the VDC process. (Sacks, et al., 2018)

Provision of context for status data collection on site/off site

Lastly, BIM provides status data on site/off site which reduces production variability by reporting and responding rapidly to workflow problems. It provides information about inventories and batches; therefore, it helps to reduce them. The status data also helps to allocate work for continuous workflow by using the pull system. It contributes to continuous improvement because the status data is reported, and the performance is accurately measured. The data of the real time status helps the verification and validation of the process information. Ultimately, it allows the manager to check the process without seeing it directly on site.

8.1. Construction Management Systems with BIM and Lean

LPS was designed to be operated without the presence of information technology. However, the use of BIM could solve problems regarding the difficult communication between trade contractors, suppliers, construction management team, designers and inspectors. The difficult communication exists because of the physical distance in the site, the focusing on individual optimisation instead of the project optimisation, lack of reporting of project status, dependence on key individuals to communicate critical information and the reliance of paper documents for product information. (Sacks, et al., 2010a)

Sacks, et al. (2010) and Dave, et al. (2015) stated that LPS has a long lookahead planning. However, in the dynamic production in construction, an instantaneously control is needed. Therefore, in order to solve this problem, two solutions of construction management systems have been proposed, KanBIM and VisiLean. They will be explained below.

Some BIM functionalities that contribute to solve the communication problems and therefore, related to these construction management systems are; the visualisation of process status, the online communication of product and process information, and the status data collection on site, all explained in the previous section.

8.1.1.KanBIM

KanBIM approach seeks to help implement the pull system in LPS through the help of the information technology. The terminology comes from Kanban, which is a system that provides flow signal to the workers and allows them to adjust the flow through the visualisation of the process. At the construction site, it is hard to visualise and communicate the flow of the process status because the workers team move from a place to others. (Sacks, et al., 2010a)

Sacks, et al. (2010) hypothesized that "*a software system that supplements the LPS by providing ubiquitous access to 3D visualizations of process status and future direction, delivered to all on site and enabling real-time feedback of process status, including Kanban card type pull flow control signals and Andon alerts, can empower people to manage the day-to-day flow of construction operations with greater reliability and less variability than can be achieved without such a system*". (Sacks, et al., 2010a)

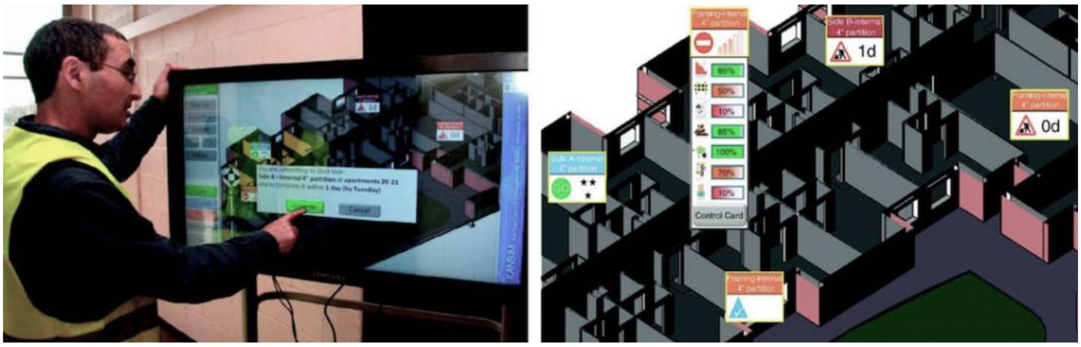

Figure 8.2 Trade crew leader reporting work status in KanBIM. (Sacks, et al., 2010a)

8.1.2. VisiLean

VisiLean is an information management system that was proposed by Dave. It is based on the following four components:

- Production planning and control workflow; LPS is used for long, medium and short planning and constraint analysis and management.
- Process and product integration; which allows the visualisation of the production planning from LPS, the BIM model and the mapping of the tasks in the model. This increases the plan reliability since the process information is continuously updated.
- Visual controls and information in production; VisiLean facilitates the pull system by providing the visualisation of the construction workflow, based on Kanban and Andon alerts.
- Lastly, it also supports the communication among the project team. (Dave, et al., 2015)

9. Impact of BIM on LPS

This chapter will present how the several BIM functionalities can benefit LPS. It will also contain an analysis of which among these BIM functionalities has a higher impact on LPS with a later description of it.

BIM can also support LPS in the design phase. However, this report will only focus on LPS during the construction phase.

BIM and its previously explained functions like 3D visualisation, 4D simulation, clash detection can improve the collaboration among the members of the project team and combined with LPS, it helps reduce the variability of the construction process. (Bhatla & Leite, 2012)

9.1. Bhatla & Leite's Integration Framework

Bhatla & Leite (2012) proposed three steps to integrate BIM with LPS. The integration framework is displayed in Figure 9.1 and explains how BIM should be used during the LPS process.

First of all, from the milestones, the Phase Schedule is stablished in 4D with the help of the subcontractors. Then, through the BIM coordination meeting and 4D scheduling, the work that **should** be done is selected and sequenced, and then placed on the Lookahead Schedule. The tasks that are not sound, are made ready by screening and pulling, MEP clash detection is also used to confirm that the activities **can** be done and therefore, added to the workable backlog. Lastly, only the activities without MEP clashes are selected and sequenced in the Weekly Work Plan, which is where the activities **will** be done.

The reliability of the plan through LPS is more improved with the use of the 4D model and its construction simulation to see the desired progress of the project, to look for construction alternatives in order to better plan the workflow.

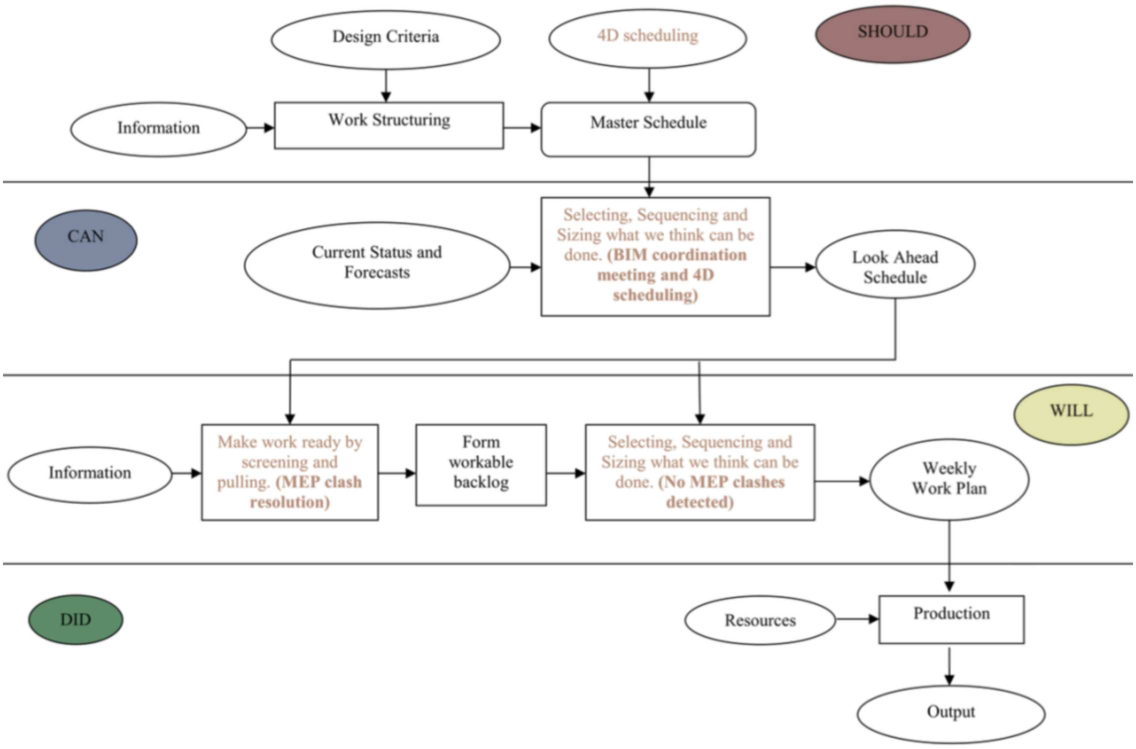

Figure 9.1 Integration of BIM with LPS. (Bhatla & Leite, 2012)

MEP clash detection also increases the workflow reliability on the Weekly Work Plan. Through the use of this framework in a case study, Bhatla & Leite (2012) stated that it reduced the Requests for Information (RFI) and change orders issued; therefore, it increased the value for the costumer.

9.2. Benefits of BIM on LPS

Bhatla & Leite's BIM with LPS Integration Framework and the construction management systems using BIM and LPS, section 8.1; showed how BIM can be applied with LPS. However, Table 9.1, Table 9.2 and Table 9.3 are developed to show the many different BIM functionalities that can be also applied, in each stage of the LPS with its respective benefits that have on the stage. Note that some BIM functionalities might be used in more than one stage of LPS. The functionalities and the benefits are taken from several articles that will be specified.

Phase of LPS	BIM functionality that benefits LPS	Benefit on LPS
Phase Schedule (SHOULD)	Visualise and review the construction sequence to identify problems before executing the work. (Tillman & Sargent, 2016)	• Identify problems or safety issues before executing the work. • Helps making decisions. (Tillman & Sargent, 2016)
	BIM allows the simultaneous visualisation of the different MEP systems. (Tillman & Sargent, 2016)	• Work quality improvement • Helps making decisions. (Tillman & Sargent, 2016)
	Visual reports using Construction Hazard Assesment with Spatial and Temporal Exposure (CHASTE) methods. (Sacks, et al., 2009)	• Filter work by evaluating if the assignments are safe enough. (Sacks, et al., 2009)
	BIM models on digital touch screens on Big Room. (Fosse, et al., 2017)	• Improve communication and understanding during meetings. (Fosse, et al., 2017)

Table 9.1 BIM benefits during Phase Schedule.

Phase of LPS	BIM functionality that benefits LPS	Benefit on LPS
Lookahead (SHOULD-CAN)	Model accessibility in the field. (Tillman & Sargent, 2016)	• Compare and document discrepancies and quickly inform the project team. • Increase communication and facilitate problem solving and constraints removal. (Tillman & Sargent, 2016)
	Visual status charts that show readiness of equipment, worker, space, materials, information etc. (Sacks, et al., 2009)	• Filter work packages for maturity to ensure stabiity. (Sacks, et al., 2009)
	Visual reports using Construction Hazard Assesment with Spatial and Temporal Exposure (CHASTE) methods. (Sacks, et al., 2009)	• Filter work by evaluating if the assignments are safe enough. (Sacks, et al., 2009)
	3D visualisation and MEP clash detection. (Bhatla & Leite, 2012)	• No future collisions during construction. • Reduce RFI and change orders issued. • More value for the customer. (Bhatla & Leite, 2012)
	BIM models on digital touch screens on Big Room. (Fosse, et al., 2017)	• Improve communication and understanding during meetings. (Fosse, et al., 2017)

Table 9.2 BIM benefits during lookahead process.

Phase of LPS	BIM functionality that benefits LPS	Benefit on LPS
Weekly Work Plan and daily work (WILL - DID)	Visualisation of process status. (KanBIM) (Sacks, et al., 2010)	• Execute tasks with little delays. • Helps allocate work for continuous workflow using pull system. • Manager can follow the process up. (Sacks, et al., 2010)
	Online communication of product and process information. (KanBIM) (Sacks, et al., 2010)	• Identify conflicts when the product information is updated. • Allows the communication between team members. • Execute tasks with little delays. • Helps allocate work for continuous workflow using pull system. • Online accessibility by the workers to the standards of the production to visualise the production methods. • Helps making decisions. (Sacks, et al., 2010)
	Visual reports using Construction Hazard Assesment with Spatial and Temporal Exposure (CHASTE) methods. (Sacks, et al., 2009)	• Filter work by evaluating if the assignments are safe enough. (Sacks, et al., 2009)
	Status data collection on site. (KanBIM) (Sacks, et al., 2010)	• Reporting and responding rapidly to workflow problems. • Provides information about inventories and batches. • Helps allocate work for continuous workflow using pull system. • Data is imported and the performance is measured. Continuous improvement. • The manager can check the process without seeing on site. (Sacks, et al., 2010)
	Computer controlled fabrication. (Sacks, et al., 2010)	• Transfers the product data without human mistake. (Sacks, et al., 2010)

	Integration with project partner (supply chain) databases. (Sacks, et al., 2010)	• Direct information for ordering materials. • Helps pull system by delivering material or design information when is required. • Improves the relationship with the project partners. (Sacks, et al., 2010)
	Analysis of plan failures and data generated through LPS. (Tillman & Sargent, 2016)	• Gaps identification in the model that can be improved. (Tillman & Sargent, 2016)
	Last planner tablet application for crew. (Fosse, et al., 2017)	• Production schedule accessible and updated. • Allows the workers to suggest changes, commit activities and report progress. (Fosse, et al., 2017)
	BIM models on digital touch screens on Big Room. (Fosse, et al., 2017)	• Improve communication and understanding during meetings. (Fosse, et al., 2017)

Table 9.3 BIM benefits during WWP and daily work.

The development of the tables revealed that the WWP and daily work phase of the LPS contains the highest amount of BIM functionalities, among the ones that are mentioned in this section.

9.2.1. Impact of BIM on the Benefits of LPS

This section analyses how the several already mentioned BIM functionalities that benefit LPS have impact on the benefits of LPS. Table 9.4 displays with a “X” wherever that BIM functionality enhances the corresponding benefit of LPS. The positions of some “X” were determined according to their respective literature, others were placed based on the knowledge that I gained through the development of the report. The benefits of LPS used for this analysis are extracted from section 5.5, called LPS Benefits.

BIM functionalities \ LPS benefits	Production reliability	Less cycle time	Supply chain instability	Improve communication among participants	Less day-to-day problems and stress on-site	Quality of work improvement	Knowledge expansion and learning	Improvement of managerial practices
Visualise and review the construction sequence to identify problems before executing the work.	X	X					X	
BIM allows the simultaneous visualisation of the different MEP systems.		X				X		
Model accessibility in the field.	X			X				X
Visual status charts that show readiness of equipment, worker, space, materials, information etc.	X	X		X	X			X
Visual reports using Construction Hazard Assesment with Spatial and Temporal Exposure (CHASTE) methods.					X			
3D visualisation and MEP clash detection.	X	X			X	X		
Visualisation of process status. (KanBIM)	X	X	X	X				X
Online communication of product and process information. (KanBIM)	X	X	X	X	X	X	X	X
Computer controlled fabrication.		X	X	X	X	X		
Integration with project partner (supply chain) databases.	X	X	X	X		X	X	
BIM models on digital touch screens on Big Room.	X	X	X	X			X	
Status data collection on site. (KanBIM)	X	X		X	X			X
Analysis of plan failures and data generated through LPS.						X	X	
Last planner tablet application for crew.	X	X		X				

Table 9.4 Impact of BIM on the benefits of LPS.

The results of the analysis made in Table 9.4 are shown in Figure 9.2. The benefits of LPS are shown orderly, from higher to lower number of interactions that have from the BIM functionalities.

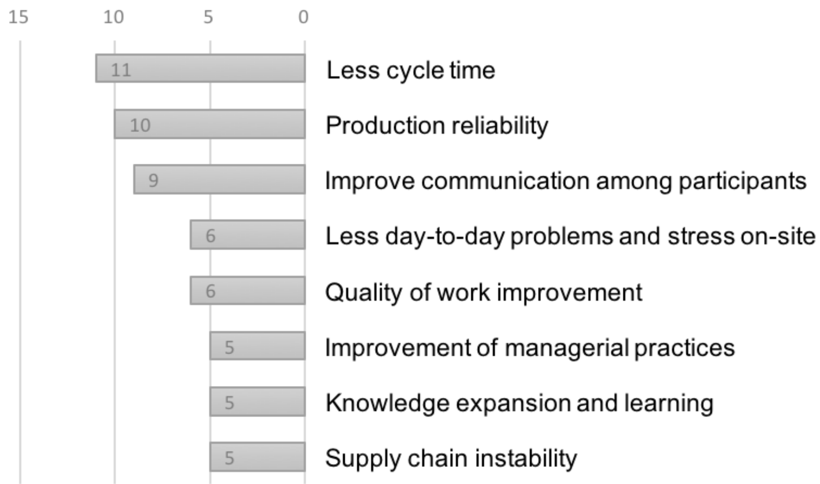

Figure 9.2 Interactions of benefits of LPS.

By looking at Figure 9.2, one can observe that the use of BIM together with LPS helps mostly improve the benefit of reducing the production time. It also increases the production reliability and lastly, enhances the communication among participants.

On the other hand, it has to be mentioned that the BIM functionalities that have higher amount of impacts in the benefits of LPS are the ones related mainly to the KanBIM approach that was previously explained in section 8.1. These BIM functionalities include the status data collected on site, the visualisation of the process status, the visualisation of readiness of preconditions and lastly, the online communication of product and process information. In addition, the supply chain databases also have a high increment on the benefits of LPS.

As a result of the analysis, one can observe that this mentioned five functionalities have something in common. They all have the characteristic that are connected to the communication of information in construction.

Sacks, et al. (2018) stated that information does not only refer to product information, it also refers to process information. Process information consists of the status of various flows; such as flow of work, material, crews, equipment, product information and money. It has been demonstrated that using a clear and full communicating process with visual help, like production control and Andon boards, pull kanbans and use BIM models to collect and deliver process and product information can improve the workflow. (Sacks, et al., 2018)

9.3. Communication in Construction

In the planning process of LPS, the teams need information about the different resources of the construction tasks in order to elaborate the lookahead and the weekly planning. (Dave, et al., 2015) "*In a fragmented and dynamic environment, the integration and exchange of information between various organisational information systems and sources is crucial for efficient production management.*" (Caldas, et al., 2005)

According to Dave, et al. (2015), the lookahead planning is one of the hardest processes of LPS since in traditional construction there is no IT tool used to anticipate the impact of the constraints on workflow reliability before the execution week. Researchers have tried to solve this problem by proposing resource management platforms like KanBIM, explained in previous chapter. Nevertheless, KanBIM is designed for the data input of the workers in the site, the service does not apply necessarily for the suppliers. Therefore, KanBIM does not solve the problem of complexity and distributed information systems in construction supply chains.

The information about the status of the constraints is one of the most important information in production planning, the make-ready process and the execution process. In the use of LPS, it is important to make this resource information available, visual, synchronised with all systems and easily understandable. (Dave, et al., 2015)

Dave proposed an information management system called VisiLean, and together with KanBIM, both explained in section 8.1, are integrated with the building model in a visual way and they improve the collaborative production management. However, they have the weaknesses of not solving the heterogeneity of the information sources, not avoiding the fragmentation and not supporting completely push and pull mechanisms that have an important impact on the control. (Dave, et al., 2015)

According to Dave, et al. (2015), it is needed a more generic communication system that closes the loop between head office, site office and field providing feedback as shown in Figure 9.3.

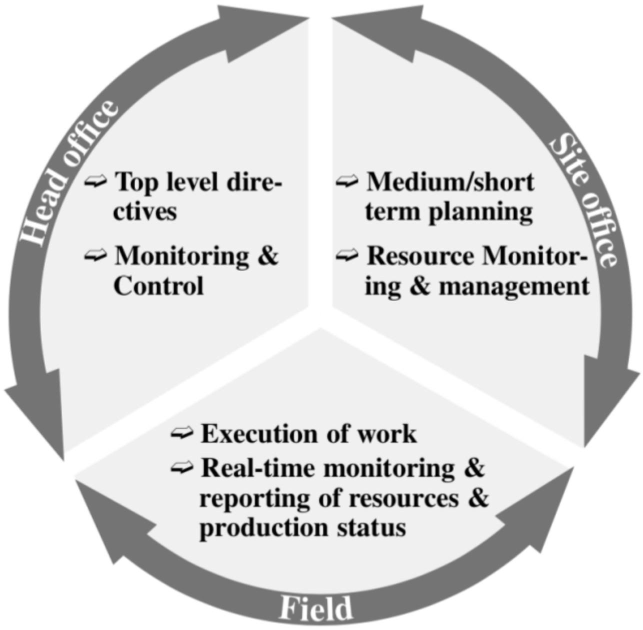

Figure 9.3 Communication loop. (Dave, et al., 2015)

9.3.1. Types of Information to Be Pushed

Dave, et al. (2015) clasified the different types of information that has to be pushed to the work teams during the construction management system. The clasification is as it follows.

Medium Term Plan

In the lookahead planning, task leaders have to remove the constraints before the meeting for the WWP. As the crews spend most of the time at the field, they should be provided with an easy-to-use interface in order to modify in the field the status of the constraints.

Execution Plan

It consists of the information given to the workers at the field containing the tasks they have to do for the week, location, resources, constraints and linked to the BIM model.

Production Status Monitoring and Control

It is the information communicated to the workers to be guided during the execution. It refers to current status of relevant tasks, changes of the plan, approaching execution or constraint removal deadlines.

Production Status Reporting

This information refers to the one communicated by the workers, like the task starting, stopping, completing or any arisen problem. Workers notify their foremen in a daily or weekly basis. However, it would be beneficial that this information is pushed directly from the workers to the production management system.

Automated Resource Tracking

Through electronic procurement systems, a notification of the resources delivery can be automatically sent. Moreover, it is also possible to track the location of the incoming resources.

9.3.2.Internet of Things Standards

To solve the already mentioned problems in communication regarding the fragmentation in VisiLean and KanBIM systems, Dave, et al. (2015) investigated how the use of Internet of Things (IoT) standards can improve the communication in such construction management systems and therefore, close the communication loop shown in Figure 9.3 between the head office, the site office and the field.

Figure 9.4 shows on the right side the three components that are incorporated in VisiLean and how they are connected through IoT standards to resource management and production control. The Open Messaging Interface (O-MI) is a IoT standard that provides the interface to exchange construction information between several types of nodes; VisiLean, phones, RFID system etc.

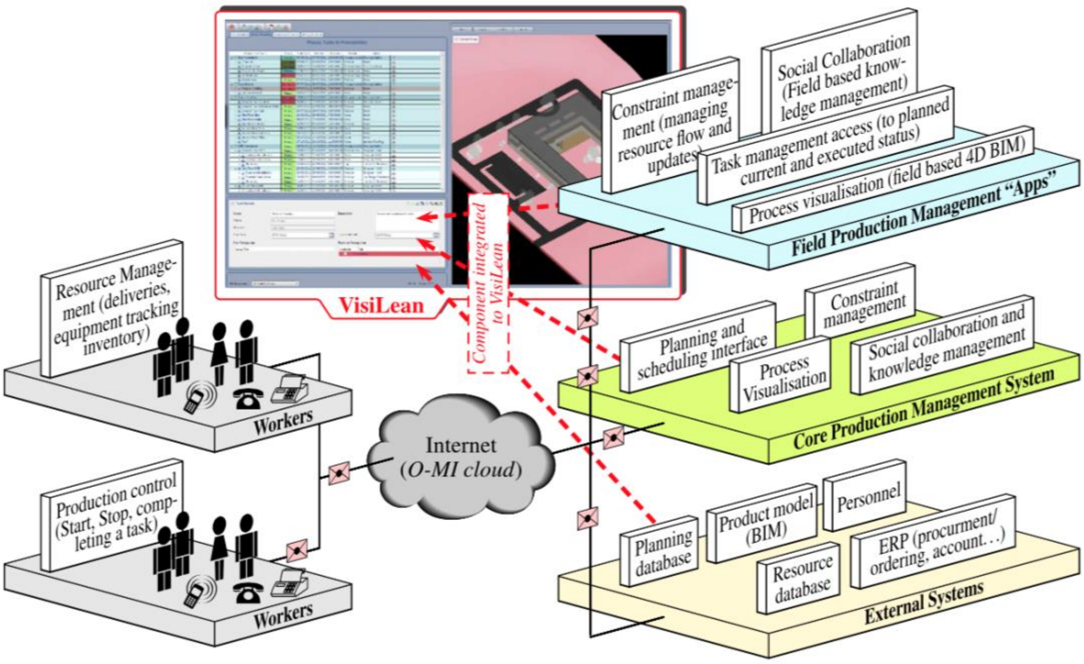

Figure 9.4 Diagram of Visilean and IoT use in construction management. (Dave, et al., 2015)

The use of IoT standards in construction management provides mainly the following possibilities:

- The resources can be tracked at any stage since IoT allows the use of tracking tools, such as RFID, QR, GPS etc.
- Update the real time production information through mobile apps by the workers. In case devices are not available, a magnetic board can also be used for assigning the task status. The magnetic board provides an easy visual information to the workers. Moreover, a camera can take pictures of the magnetic board and push the information though the system.
- Automated procurement can be achieved by providing interfaces among workers, managers and suppliers. (Dave, et al., 2015)

10. Process of BIM and LPS

Throughout this chapter, it will be developed and explained the process of LPS when BIM is integrated. This has the purpose of being used as a help for implementation or as work models for a future system development.

The combination of BIM and LPS approach has the purpose of using the information contained in the building model to support the operation coordination on construction site (Sacks, et al., 2010a). The information that is generated, how it is distributed and the activities in which the information is produced are displayed along this chapter. In order to simplify it and make it more understandable, it has been divided in two figures. Figure 10.2 contains the BIM functionalities for each LPS process, whereas Figure 10.3 contains the information about which actors are executing each process.

The LPS process used in both figures are based on several diagrams from Ballard (2010), Sacks, et al. (2010) and Bhatla & Leite (2012).

A process flowchart shows the different steps of a process in a sequential order from start to finish. In this case, the process is for LPS, and how BIM is used to increase its benefits and functionalities. The process flowchart can be used mainly to explain, communicate and understand how a process works. Other functions of a flowchart would be for training, to document a process or examine efficiency. (Fredrick, n.d.) Or lastly, as a work model, which is a step of Contextual Design Process (CDP) as it will be shortly explained below.

Contextual Design (CD) is a user-centered design process that brings methods to collect, interpret and structure data from users in order to create a product or service, and test and refine it with the users. The structure of the Contextual Design Process (CDP) is represented in Figure 10.1. CDP is divided in two parts; the first part corresponds to the requirements and solutions, shown in the light gray boxes; whereas the second part consists of the definition and validation of concepts, shown in the dark gray boxes. (Holtzblatt & Beyer, 2014)

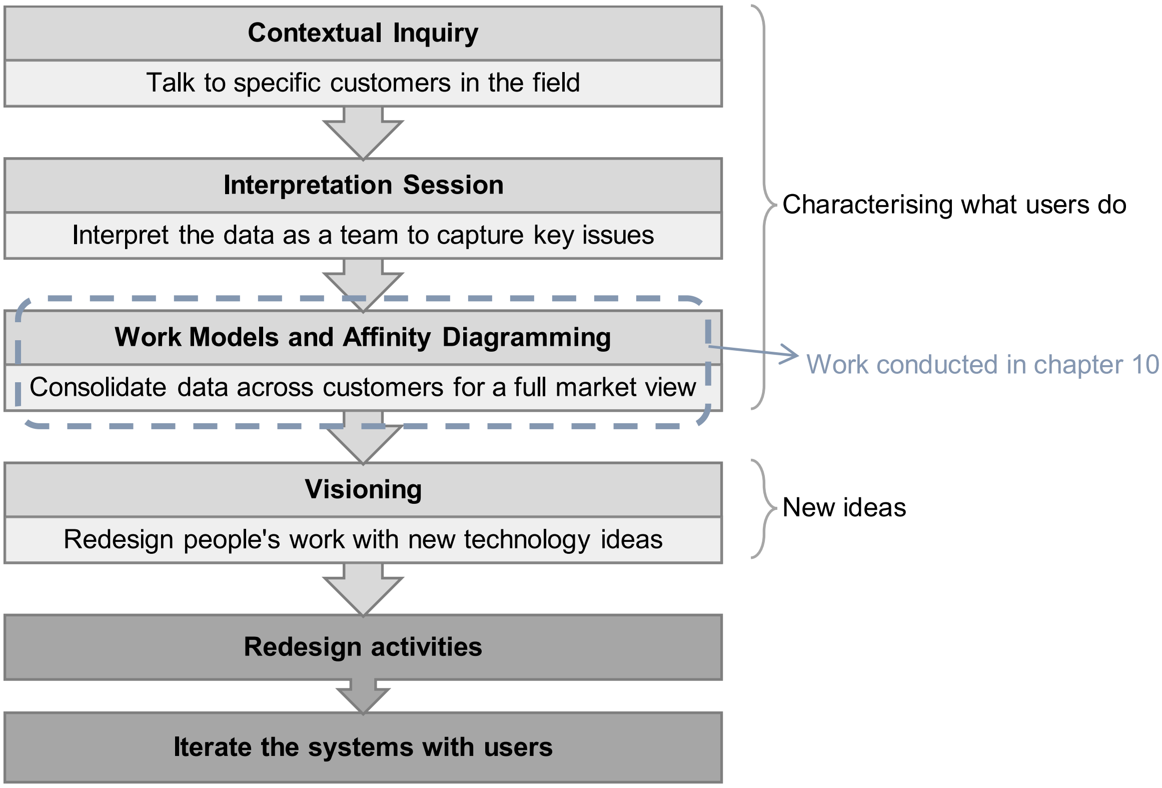

Figure 10.1 Contextual Design Process (Amended from (Holtzblatt & Beyer, 2014)).

As stated in Figure 10.1, the first three steps of CDP are related to characterising what users do. After understanding and collecting information from the users, and interpreting the data collected, work models and diagrams are executed as a next step.

According to Holtzblatt & Beyer (2014), work models are used to represent the work or processes in diagrams. Work models are utilised because work and processes are complex and full of details. Therefore, it is hard for the design teams to see in detail how the structure of that work is, to be able to develop new ideas in the *Visioning* step.

Different types of work models can be made to provide different perspectives. Firstly, Flow Model is one of them and it shows how the work is processed, the communication between the participants and the different roles and responsibilities. Secondly, Sequence Model provides the steps that have to be taken in order to carry the work out. (Holtzblatt & Beyer, 2014)

Figure 10.2 can be used as a Sequence Model. Whereas Figure 10.3 will be used to develop the Flow Model, displayed in Figure 10.4.

The process flowchart shown in Figure 10.2 corresponds to the Sequence Model and describes the processes of the LPS in the different stages, which are shown in the white rectangles. Moreover, it also shows how the several BIM functionalities interact with those LPS processes, the grey rectangles. After the figure, it will be explained in detail how LPS and BIM interact with each other.

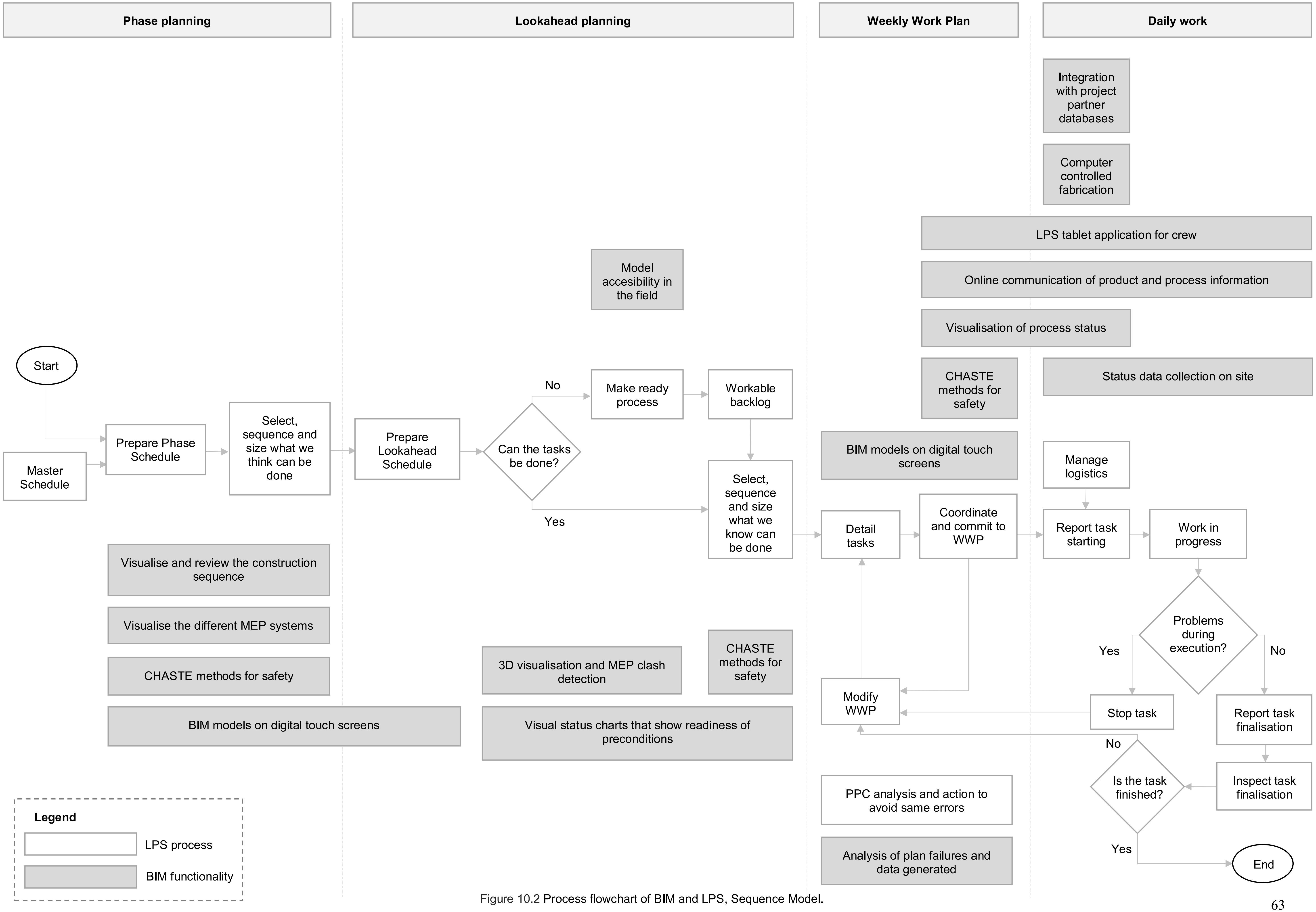

Figure 10.2 Process flowchart of BIM and LPS, Sequence Model.

The flowchart is divided into the four following phases; phase planning, lookahead planning, WWP and daily work.

The beginning of the flowchart corresponds to the phase planning where the Master Schedule is used to prepare the Phase Schedule with the help of the subcontractors by selecting, sequencing and sizing what they think can be done. In this phase, several BIM functionalities can be used to help the process. To visualise and review the construction sequence can help identify problems and making decisions. The simultaneous visualisation of the different MEP systems increases the work quality and it also helps make decisions. The CHASTE methods are used to filter the tasks for safety reasons. Lastly, the BIM models on digital touch screens improve the communication and understanding during the meetings.

The lookahead planning phase starts with the process of taking the activities from the Phase Schedule and placing them in the lookahead window. Next step is the screening and pulling where the activities have to be analysed if they can be done by checking their preconditions and in case the tasks cannot be done, the constraints will be removed and then added to the workable backlog. Regarding the BIM functionalities, 3D visualisation and MEP clash detection confirm that the tasks can be done without collisions. The visual status charts show the status of the preconditions and filters the activities to ensure stability for the WWP. CHASTE methods can also be used to provide safety in the tasks by filtering the work and sequencing it as required. Furthermore, the model accessibility in the field increases the communication and facilitates the constraint removal in the make ready process.

The next stage of the LPS corresponds to the WWP. In the WWP, the tasks are sound and collected from the lookahead window. Digital touch screens can be used to detail the tasks for each subcontractor for the week. Once the tasks have been detailed, the coordination between trades and the commitment must take place. For this coordination, many BIM functionalities can be used, which are explained in the following. CHASTE methods for coordinating in a safety way. The visualisation of process status and the online communication of product and process information can coordinate the work among trades in case a problem occurs during construction. The LPS tablet application allows the workers to suggest changes and commit activities. Lastly, the PPC analysis of LPS can be made easily through the analysis of plan failures and data generated and identifying the gaps in the model that can be improved.

The last part of the process refers to the daily work. Once the trades have committed to execute the tasks and the logistics are managed for the same purpose, the activities have to be reported anytime they are started. In order to facilitate the logistics management, BIM provides the functionalities of integration with project partner databases and computer-controlled fabrication which provides direct information for ordering materials and helps pulling material or information when it is required. Furthermore, the visualisation of the process status helps managing the logistics and allocate work when a problem occurs. The report of the task starting can be supported by the online communication of product and process information and LPS tablet application that reports progress and helps collecting status data on site. When a task is being executed it could be stopped because of a problem during execution which would lead to the WWP modification and the previous mentioned steps of the WWP to ensure continuous workflow. However, if any problem exists during execution the task is reported as finished which will later be inspected for confirming completion or to modify the WWP in case that is not finished yet. All these steps can be reported through the online communication and the status data collection on site the LPS tablet application offers to the workers.

Figure 10.3 represents another process flowchart where the different actors of the process are placed in the different swim lanes according to which task they are responsible for. The actors are placed in the horizontal swim lanes, whereas the vertical swim lanes stand for the different phases of LPS. The LPS processes contained in white rectangles are linked with the actors on its corresponding swim lane. Whereas the grey rectangles refer to the activities that does not have actor to be linked with. One of the purposes of this flowchart development is to serve as a basis for the creation of the Flow Model, which will be displayed in Figure 10.4.

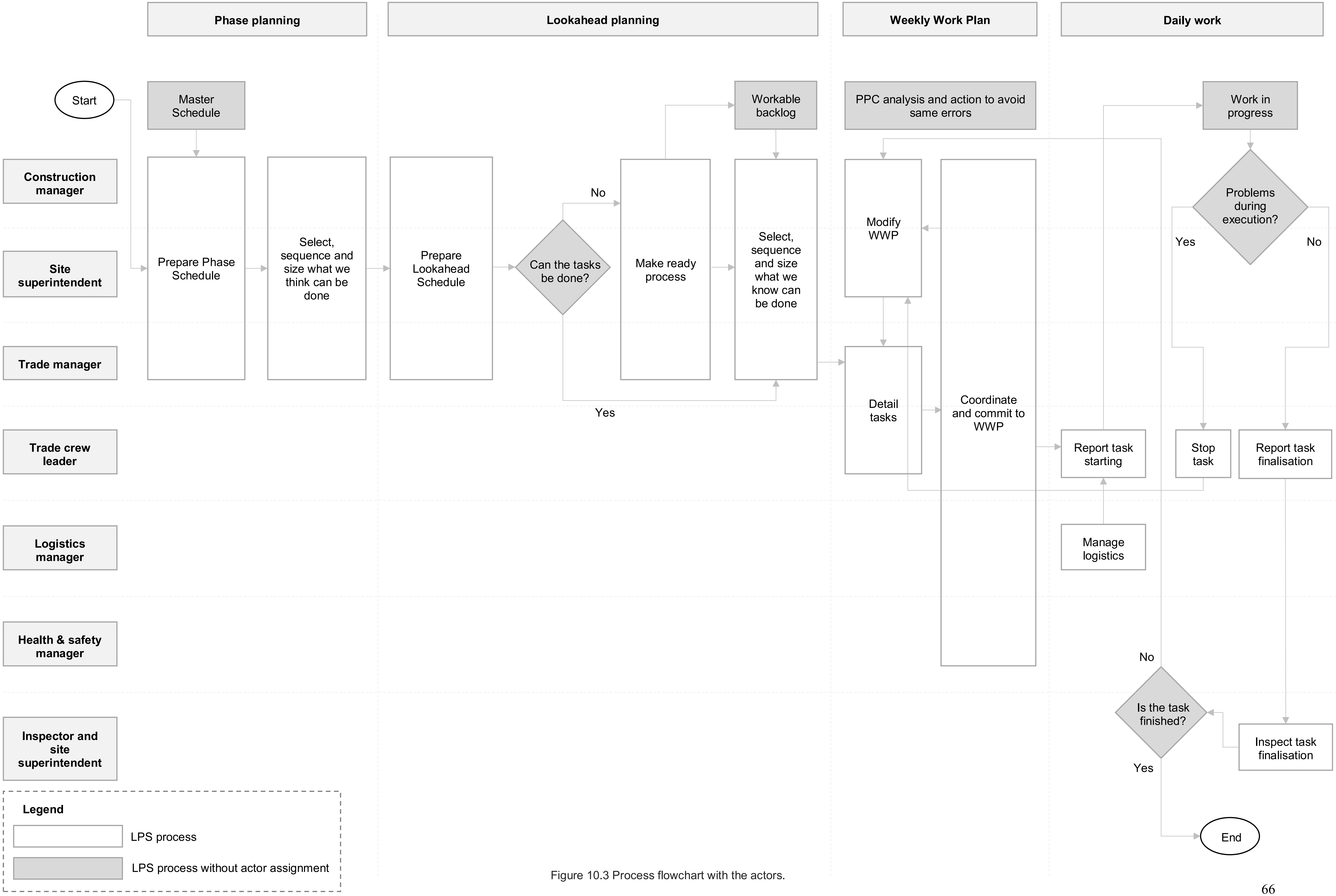

Figure 10.3 Process flowchart with the actors.

Figure 10.4 represents the second work model, namely Flow Model. The model displays the different actors located in the small circles. Moreover, it also includes the roles, responsibilities and tasks that are executed between the participants, it is shown by the circles containing tasks and participants in it. The different colours of the circle show the several phases of LPS. Lastly, the Flow Model shows the communication in construction between the actors. In the figure, the communication is shown by the arrows that corresponds to the information that has to be pushed, according to Dave, et al. (2015), mentioned and explained in section 9.3.

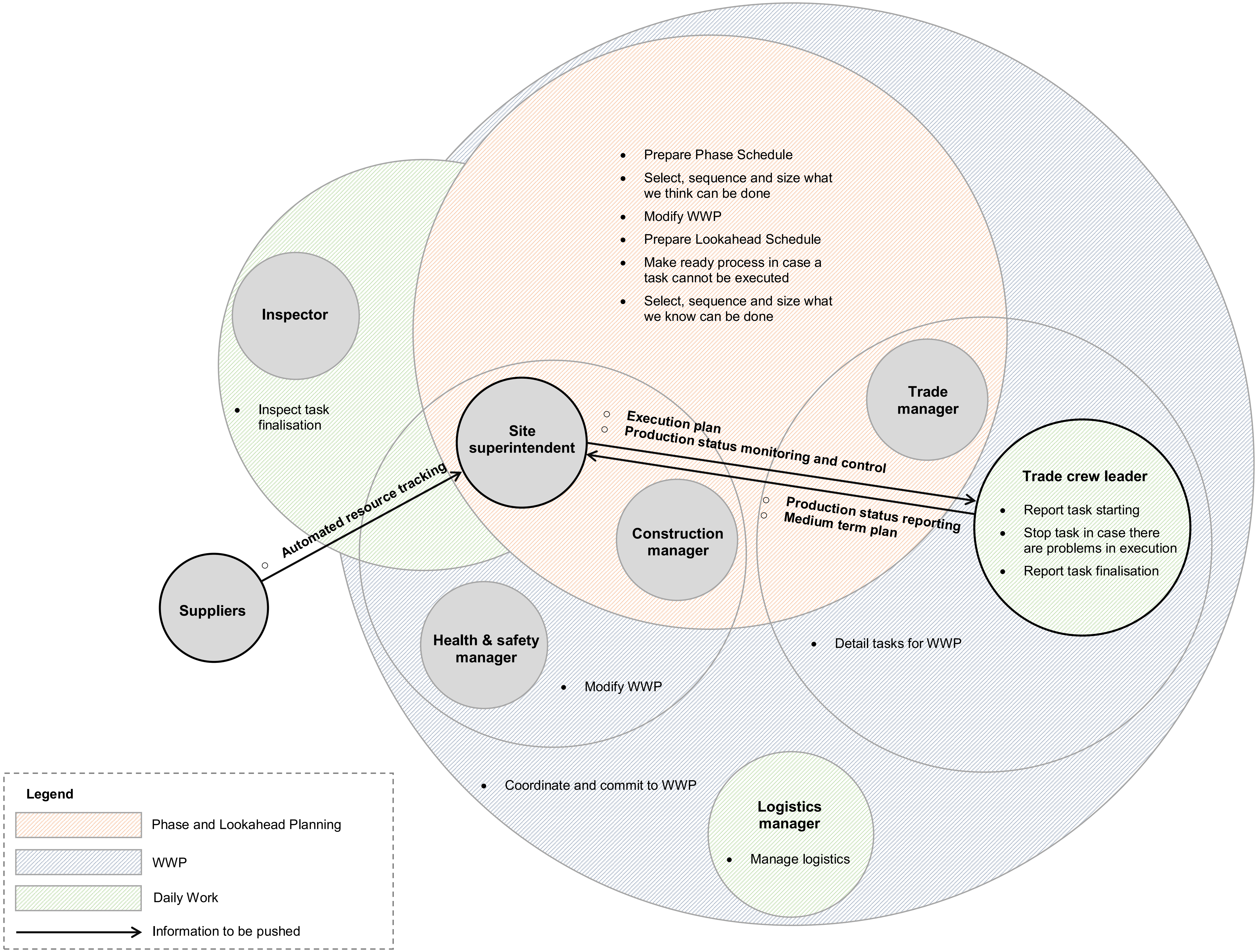

Figure 10.4 Flow Model.

PART IV. CONCLUSION

11. Conclusion

Throughout basically the whole report, a systematic review has been carried out mainly focusing on BIM and LPS, as a main two topics. Literature review was used in Part II, to display a theoretical background to provide the necessary knowledge for the report. Moreover, in Part III, literature review is also used in order to investigate how a project can be optimised through their combination answering the tittle on the thesis. To be able to guide the review, one research question with three sub questions were formulated and they were answered in the Solution, Part III.

- How can BIM benefit the use of LPS?
    - How can BIM contribute to Lean in the construction phase?
    - Which BIM functionalities have higher impact on LPS and how are they applied?
    - How can the process that integrates LPS with the use of BIM be developed for a later implementation or system development?

Chapter 8 aimed to give answer to how BIM can contribute to Lean Construction. In order to do so, the study of Sacks, et al. (2010) was examined in detail. Therefore, it can be concluded that BIM has multiple contributions to Lean during all phases but also during the construction phase. Moreover, BIM can also be used as construction management systems to help implementing Lean Construction. These systems are KanBIM and VisiLean.

The sub question regarding the impact that the BIM functionalities have on LPS is solved in Chapter 9. All the BIM functionalities were gathered through the literature review and analysed in a chart with the benefits of LPS. The conclusion was that the benefits of LPS that were higher impacted were; less cycle time, production reliability and improved communication among participants. On the other hand, the BIM functionalities that had higher impact on the LPS benefits were the ones related to communication in construction. Furthermore, the several types of information in construction to be communicated seems to be important and the IoT could help to solve the problems that the previous mentioned management system could have in terms of fragmentation because of several devices for instance.

Lastly, Chapter 10 focuses on developing the process of BIM combined with LPS as the answer of the last sub question. Two process flowcharts were developed, one contained the process of all the phases of LPS and the BIM functionalities, whereas the other flowchart included the actors in the LPS process when BIM is used. Moreover, it was stated that they can be used for the implementation or as a work model, namely Sequence Model, in a CDP for a system development. Furthermore, a Flow Model was also elaborated through the flowchart containing the actors.

12. Reflection

This chapter reflects what could have been done differently and things that could be investigated further in the future.

Regarding things that could be further elaborated; first of all, it would be the continuation of the CDP. Another work models could be carried out. Moreover, the development of ideas for a new system. Secondly, an analysis of the contribution of BIM to the use of LPS during the design phase could also be elaborated.

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