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Department of Management and Production Engineering

Master of Science in Engineering and Management

Master Thesis

BIM in Construction Management: Leaning the Design-Bid-Build (DBB) Project Delivery System by Using BIM in Design Phase

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Summary

Design phase of construction projects can be improved by utilizing new tools and methods introduced by building information modeling (BIM) and lean construction. However, in the projects that use BIM, roles of personnel, design methods and the practice of communication between designers often derive from the era of document-based design management and can only be partially adapted to a new way of working. In managing building design, the use of lean management tools can be seen a driver increasing value to the customer, improving operations and removing activities that do not add value.

This research has focused on the design phase of Design-Bid-Build project delivery system (DBB). DBB is the most traditional type of delivery method practiced today. In this method the owner has two contracts: one with the architect and one with the contractor. DBB is considered a linear process because there is no overlap of the architectural services and the contractor services. In a perfect world the process is that simple, but in reality, a number of challenges may arise. First, it is possible that the low bid is not as low as the owner expected it to be. As mentioned, the architect and engineers create the drawings and specifications with little to no contractor input. This may lead to miscalculations on what is required to construct their design. this scenario is unfortunately very common in DBB and can lead to a slow construction start due to the design-bid-redesign-bid-build process. Another challenge that may arise in DBB is that gaps or errors are found in the design once the contractor has already begun to build the project.

The research consists of a literature review and an empirical investigation. In the literature review, previous studies and their results related to application of BIM and LEAN construction in different project delivery systems, their synergies and interoperability, and information flows of traditional 2D and BIM-based design of the construction projects are examined along with the professional journals and text books of the construction industry. Value stream

mapping (VSM) is used to model, analyze and compare the information flow in traditional 2D design (as the current state) and BIM-based design (as the future state). Empirical data was collected from semi-structured interviewees with experienced engineers whom involved and have experiences with the subject of research and finally validate the model which has proposed by the research.

The results of the research demonstrate that use of BIM-based design and lean concepts in the DBB project delivery system leads to efficiency of information flow, improve communication and collaboration, target value design and waste management in design phase. In bidding phase BIM technology can comprehensively enhance the working efficiency of the construction bidding, calculate the engineering quantity list accurately, improve the rationality of bidding quotation and management level, show the information of funds in various stages of the bidding and can help to enhance the competitive advantage of the tender bidding company. Also, it will cause the reduction of construction cost and time and less conflicts in construction phase and better performance in maintenance phase of project.

Chapter 1

Theoretical Overview

1.1 Building Information Modeling

1.1.1 What is BIM?

There is no definite definition of BIM but there are many ways of interpreting what BIM is. For some BIM is a software application and for others is a process for designing and documenting building information (Aranda-Mena, 2009). A contractor defines BIM as a process, designers define it as intelligent 3D models, while most other professionals define BIM as a visualization tool in construction (Barlish, 2012).

Building information modeling can be defined as: “The process that is focused on development and use of computer-generated model to stimulate the planning, design, construction and operation of facility (Azhar, 2008).

American Committee of the National Information Model Standard Project Committee defines BIM as “a digital representation of physical and functional characteristics of a facility...and a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.” (NBIMS, 2007). This definition of BIM contains adequate life cycle building information and does not refer only to one group of stakeholders; thus, it is used as the underlying definition and purpose of BIM for this research.

Another document issued by British Standard Institution Specification for information management for the capital/delivery phase of construction projects using building information modelling defines BIM as "the process of design, construction and use of the building or facility infrastructure using information about virtual objects" (PAS 1192-2, 2013)

BIM is a visualization tool that enhances communication between architectural, engineering and construction industries. The concept is to build a building virtually, prior to building it physically, in order to work out problems and simulate and analyze potential impacts (Smith, 2007).

BIM is a process for managing the information produced during the life cycle of an asset (NBS, 2013). BIM is not just a tool or a solution (BIFM, 2012), but rather value-creating collaboration, underpinned by 3D models and intelligent structured data (BIM Industry Working Group, 2011). Variable digital models or an integrated model contain all the information about project, which is built by project participants and support the interchange of data among them. In addition to planning and design phase, the BIM method consists of cost management, construction management, project management and facility operation (IBC, 2011).

1.1.2 The BIM Process

BIM has defined as a modeling technology and associated set of processes to produce, communicate, and analyze building models. BIM is the acronym of "Building Information Modeling," reflecting and emphasizing the process aspects, and not of "Building Information Model." The objects of BIM processes are building models, or BIM models.

Building models are characterized by:

- Building components that are represented with digital representations (objects) that carry computable graphic and data attributes that identify them to software applications, as well as parametric rules that allow them to be manipulated in an intelligent fashion.
- Components that include data that describe how they behave, as needed for analyses and work processes, such as quantity takeoff, specification, and energy analysis.

- Consistent and nonredundant data such that changes to component data are represented in all views of the component and the assemblies of which it is a part.

The NBIMS vision for BIM is “an improved planning, design, construction, operation, and maintenance process using a standardized machine-readable information model for each facility, new or old, which contains all appropriate information created or gathered about that facility in a format useable by all throughout its lifecycle” (NIBS, 2008). The NBIMS Initiative categorizes the Building Information Model (BIM) three ways:

1. as a product
2. as an IT-enabled, open standards–based deliverable, and a collaborative process
3. as a facility lifecycle management requirement

These categories support the creation of the industry information value chain, which is the ultimate evolution of BIM.

Another way to characterize BIM is to define a progression of levels of maturity of application of information technology in construction that expresses the degree of collaboration in the process as well as the levels of sophistication of use of the individual tools (Sacks, Eastman, Lee, & Teicholz, 2018). In this view BIM is seen as a series of distinct stages in a journey that began with computer-aided drawing and is taking the industry into the digital age. Since the UK Government BIM Task Group adopted the concept of “BIM Levels,” the following chart and the four levels it defines (Level 0 to Level 3) have become a widely adopted definition of the criteria for a project to be deemed BIM-compliant. In figure 1, BS standards numbers refer to British Standards Institution and the description of each level is their definition (BS, 2017).

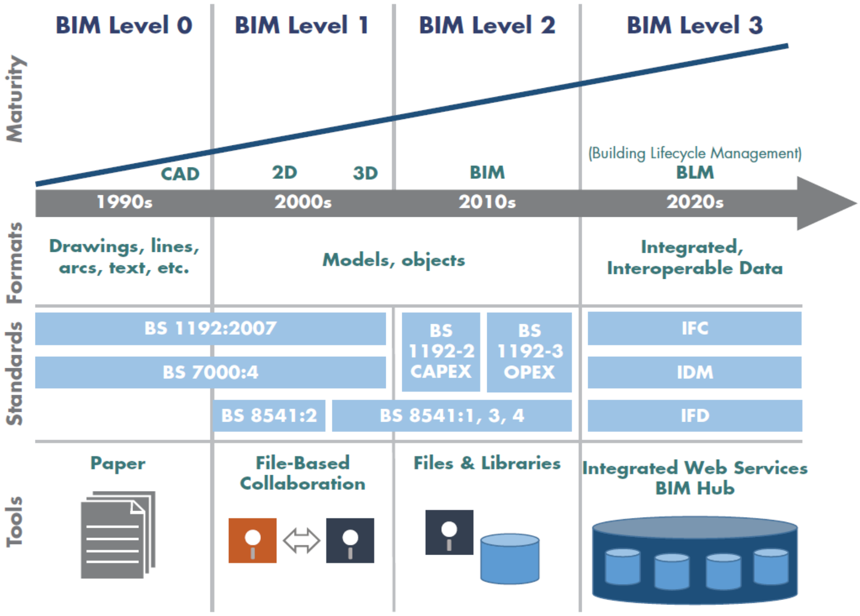

Figure 1: The BIM Maturity Model

Level 0 BIM: This level is defined as unmanaged CAD. This is likely to be 2D, with information being shared by traditional paper drawings or in some instances, digitally via PDF, essentially separate sources of information covering basic asset information. The majority of the industry is already well ahead of this now.

Level 1 BIM: This is the level at which many companies are currently operating. This typically comprises a mixture of 3D CAD for concept work, and 2D for drafting of statutory approval documentation and Production Information. CAD standards are managed to specified standards, and electronic sharing of data is carried out from a common data environment (CDE), often managed by the contractor. Models are not shared between project team members.

Level 2 BIM: This is distinguished by collaborative working—all parties use their own 3D models, but they are not working on a single, shared model. The collaboration comes in the form of how the information is exchanged between different parties—and is the crucial aspect of this level. Design information is shared through a common file format, which enables any organization to combine that data with their own in order to make a federated BIM model, and to carry out interrogative checks on it. Hence any CAD software that each party uses must be capable of exporting to a common file format such as IFC (Industry Foundation Class) or COBie (Construction Operations Building Information Exchange).

Level 3 BIM: This level represents full collaboration between all disciplines by means of using a single, shared project model that is held in a centralized repository (normally an object database in cloud storage). All parties can access and modify that same model, and the benefit is that it removes the final layer of risk for conflicting information. This is known as "Open BIM."

Thus, BIM moves the industry forward from current task automation of project and paper-centric processes (level 0) (3D CAD, animation, linked databases, spreadsheets, and 2D CAD) toward an integrated and interoperable workflow where these tasks are collapsed into a coordinated and collaborative process that takes maximal advantage of computing capabilities, web communication, and data aggregation into information and knowledge capture (Level 3). All of this is used to simulate and manipulate digital models to manage the built environment within a repeatable and verifiable decision process that reduces risk and enhances the quality of actions and product industry-wide (Sacks, Eastman, Lee, & Teicholz, 2018).

Virtual Design and Construction (VDC) is the practice of using building information modeling specifically as a first-run study of a construction process. First-run studies are standard practice in lean manufacturing and in lean construction—they support process improvement by focusing management attention very closely on the production process for the first of any series of products. With VDC, designers and builders test both the product and the construction process virtually and thoroughly before executing work in the field to construct the building. They examine integrated multidisciplinary performance models of design-construction projects, including the facilities, work processes, supply chains, and project teams in order to identify and remove constraints, thus improving project performance and the resulting facilities (Sacks, Eastman, Lee, & Teicholz, 2018).

1.1.3 Benefit of Implementing BIM

1.1.3.1 Preconstruction Benefits to Owner

Concept, Feasibility, and Design Benefits. Before owners engage an architect, it is necessary to determine whether a building of a given size, quality level, and desired program requirements can be built within a given cost and time budget. In other words, can a given building meet the financial requirements of an owner? If these questions can be answered with relative certainty, owners can then proceed with the expectation that their goals are achievable. Finding out that a design is significantly over budget after a considerable amount of time and effort has been expended is wasteful. An approximate (or "macro") building model built into and linked to a cost database can be of tremendous value and assistance to an owner (Sacks, Eastman, Lee, & Teicholz, 2018).

Increased Building Performance and Quality. Developing a schematic model prior to generating a detailed building model allows for a more careful evaluation of the proposed scheme to determine whether it meets the building's functional, sustainability, and other requirements. Early evaluation of design alternatives using analysis/simulation tools increases the overall quality of the building (Sacks, Eastman, Lee, & Teicholz, 2018).

Improved Collaboration Using Integrated Project Delivery. When the owner uses Integrated Project Delivery (IPD) for project procurement, BIM can be used by the project team from the beginning of the design to improve their understanding of project requirements and to extract cost estimates as the design is developed. This allows design and cost to be better understood and also avoids the use of paper exchange and its associated delays (Sacks, Eastman, Lee, & Teicholz, 2018).

1.1.3.2 Benefits for Design

Earlier and More Accurate Visualizations of a Design. The 3D model generated by the BIM software is designed directly rather than being generated from multiple 2D views. It can be used to visualize the design at any stage of the process with the expectation that it will be dimensionally consistent in every view (Sacks, Eastman, Lee, & Teicholz, 2018).

Automatic Low-Level Corrections When Changes Are Made to Design. If the objects used in the design are controlled by parametric rules that ensure proper alignment, then the 3D model will be free of geometry, alignment, and spatial coordination errors. This reduces the user's need to manage design changes (Sacks, Eastman, Lee, & Teicholz, 2018).

Generation of Accurate and Consistent 2D Drawings at Any Stage of the Design. Accurate and consistent drawings can be extracted for any set of objects or specified view of the project. This significantly reduces the amount of time and the number of errors associated with generating construction drawings for all design disciplines. When changes to the design are required, fully consistent drawings can be generated as soon as the design modifications are entered (Sacks, Eastman, Lee, & Teicholz, 2018).

Earlier Collaboration of Multiple Design Disciplines. BIM technology facilitates simultaneous work by multiple design disciplines. While collaboration with drawings is also possible, it is inherently more difficult and time consuming than working with one or more coordinated 3D models in which change control can be well managed. This shortens the design time and significantly reduces design errors and omissions. It also gives earlier insight into design problems and presents opportunities for a design to be continuously improved. This is much more cost-effective than waiting until a design is nearly complete and then applying value engineering only after the major design decisions have been made (Sacks, Eastman, Lee, & Teicholz, 2018).

Easy Verification of Consistency to the Design Intent. BIM provides earlier 3D visualizations and quantifies the area of spaces and other material quantities, allowing for earlier and more accurate cost estimates. For technical buildings (labs, hospitals, and the like), the design intent is often defined quantitatively, and this allows a building model to be used to check for these requirements. For qualitative requirements (e.g. this space should be near another), the 3D model can also support automatic evaluations (Sacks, Eastman, Lee, & Teicholz, 2018).

Extraction of Cost Estimates during the Design Stage. At any stage of the design, BIM technology can extract an accurate bill of quantities and spaces that can be used for cost estimation. In the early stages of a design, cost estimates are based either on formulas that are keyed to significant project quantities, for example, number of parking spaces, square feet of office areas of various types, or unit costs per square foot. As the design progresses, more detailed quantities are available and can be used for more accurate and detailed cost estimates. It is possible to keep all parties aware of the cost implications associated with a given design before it progresses to the level of detailing required of construction bids. At the final stage of design, an estimate based on the quantities for all the objects contained within the model allows for the preparation of a more accurate final cost estimate. As a result, it is possible to make better-informed design decisions regarding costs using BIM rather than a paper-based system. When using BIM for cost estimates, it is clearly desirable to have the general contractor and possibly key trade contractors who will be responsible for building the structure, as part of the project team.

Their knowledge is required for accurate cost estimates and constructability insights during the design process.

Improvement of Energy Efficiency and Sustainability. Linking the building model to energy analysis tools allows evaluation of energy use during the early design phases. This is not practical using traditional 2D tools because of the time required to prepare the relevant input. If applied at all, energy analysis is performed at the end of the 2D design process as a check or a regulatory requirement, thus reducing the opportunities for modifications that could improve the building’s energy performance. The capability to link the building model to various types of analysis tools provides many opportunities to improve building quality (Sacks, Eastman, Lee, & Teicholz, 2018).

1.1.3.3 Construction and Fabrication Benefits

Use of Design Model as Basis for Fabricated Components. If the design model is transferred to a BIM fabrication tool and detailed to the level of fabrication objects (shop model), it will contain an accurate representation of the building objects for fabrication and construction. Because components are already defined in 3D, their automated fabrication using numerical control machinery is facilitated. Such automation is standard practice today in steel fabrication and some sheet metal work. It has been used successfully in precast components, fenestration, and glass fabrication. This allows vendors worldwide to elaborate on the model, to develop details needed for fabrication, and to maintain links that reflect the design intent. Where the intent to prefabricate or pre-assemble is introduced early enough in the design process, BIM effectively facilitates off-site fabrication and reduces cost and construction time. The accuracy of BIM also allows larger components of the design to be fabricated off-site than would normally be attempted using 2D drawings, due to the likely need for on-site changes (rework) and the inability to predict exact dimensions until other items are constructed in the field. It also allows smaller installation crews, faster installation time, and less on-site storage space (Sacks, Eastman, Lee, & Teicholz, 2018).

Quick Reaction to Design Changes. The impact of a suggested design change can be entered the building model, and changes to the other objects in the design will automatically update. Some updates will be made automatically based on the established parametric rules. Additional cross-system updates can be checked and updated visually or through clash detection. The consequences of a change can be accurately reflected in the model and all subsequent views of it. In addition, design changes can be resolved more quickly in a BIM system because modifications can be shared, visualized, estimated, and resolved without the use of time-consuming paper transactions. Updating in this manner is extremely error-prone in paper-based systems (Sacks, Eastman, Lee, & Teicholz, 2018).

Discovery of Design Errors and Omissions before Construction. Because the virtual 3D building model is the source for all 2D and 3D drawings, design errors caused by inconsistent 2D drawings are eliminated. In addition, because models from all disciplines can be brought together and compared, multisystem interfaces are easily checked both systematically (for hard and clearance clashes) and visually (for other kinds of errors). Conflicts and constructability problems are identified before they are detected in the field. Coordination among participating designers and contractors is enhanced and errors of omission are significantly reduced. This speeds the construction process, reduces costs, minimizes the likelihood of legal disputes, and provides a smoother process for the entire project team (Sacks, Eastman, Lee, & Teicholz, 2018).

Synchronization of Design and Construction Planning. Construction planning using 4D CAD requires linking a construction plan to the 3D objects in a design and supplementing the model with construction equipment objects (shoring, scaffolding, cranes, etc.), so that it is possible to simulate the construction process and show what the building and site would look like at any point in time. This graphic simulation provides considerable insight into how the building will be constructed day by day and reveals sources of potential problems and opportunities for possible improvements (site, crew and equipment, space conflicts, safety problems, and so forth) (Sacks, Eastman, Lee, & Teicholz, 2018).

Better Implementation of Lean Construction Techniques. Lean construction techniques require careful coordination between the general contractor and all subs to ensure that only work that can be performed (i.e., all preconditions are met) is assigned to crews. This minimizes wasted effort, improves workflow, and reduces the need for on-site material inventories. Because BIM provides an accurate model of the design and the material resources required for each segment of the work, it provides the basis for improved planning and scheduling of subcontractors and helps to ensure just-in-time arrival of people, equipment, and materials.

This reduces cost and allows for better collaboration at the job site. The model can also be used with tablet computers to facilitate material tracking, installation progress, and automated positioning in the field (Sacks, Eastman, Lee, & Teicholz, 2018).

Synchronization of Procurement with Design and Construction. The complete building model provides accurate quantities for all (or most, depending upon the level of 3D modeling) of the materials and objects contained within a design. These quantities, specifications, and properties can be used to procure materials from product vendors and subcontractors (such as precast concrete subs).

1.1.4 Barriers of Implementing BIM

1.1.4.1 Challenges with Collaboration and Teaming

While BIM offers new methods for collaboration, it introduces new challenges with respect to the development of effective teams. How to permit adequate sharing of model information by members of the project team is a significant issue. Where architects and engineers still provide traditional paper drawings, the contractor (or a third party) can still build the model so that it can be used for construction planning, estimating, and coordination. Where designers create their design using BIM and share the model, it may not have sufficient detail for use for construction or may have object definitions that are inadequate for extracting necessary construction quantities. This may require creating a new model for construction use. If the members of the project team use different modeling tools, then tools for moving the models from one environment to another or combining these models are needed. This can add complexity and introduce potential errors and time to the project.

These issues can be ameliorated by preparing a thorough BIM Execution Plan (BEP) that specifies the levels of detail that are required from each modeler at each stage, as well as the mechanisms for model sharing or exchange. Model exchange can be file-based or use a model server that communicates with all

BIM applications. The practice of co-locating multidisciplinary design and construction teams in a “Big Room” office space—a collocated and collaborative work environment—is a very effective way to leverage the close coordination that BIM enables for improving project design quality and reducing project durations.

The collaborative and open work environment that BIM creates can also raise security concerns. For example, if appropriate steps are not taken, a detailed BIM model of a security-sensitive facility such as an airport, a railway station, or other public and private buildings may fall into the hands of people with malicious intent.

1.1.4.2 Legal Changes to Documentation Ownership and Production

Legal concerns, with respect to who owns the multiple design, fabrication, analysis, and construction datasets; who pays for them; and who is responsible for their accuracy, arose as BIM use grew (Sacks, Eastman, Lee, & Teicholz, 2018). The architecture develops the model and the clients pay for it, hens the clients pay for it then the clients require a complete ownership of data, problem arise when one of the stakeholders want to use some data of the model or modifying it at this moment this stakeholder need an authorization to do so (Azhar S. , 2011). Also one of BIM legal implementation main problem is who is authorized to do what and who is authorized to view what, and who is responsible for this modification, and who is the one who entitled to do the modification, and who carry the risk of modification (Thompson & Miner, 2006). These issues have been addressed by practitioners through BIM use on projects. Professional societies, such as the AIA and the AGC, have developed guidelines for contractual language to cover issues raised by the use of BIM technology.

1.1.4.3 Implementation Issues

Replacing a 2D or 3D CAD environment with a building modeling system involves far more than acquiring software, training, and upgrading hardware. Effective use of BIM requires that changes be made to almost every aspect of a firm's business (not just doing the same things in a new way). It requires some understanding of BIM technology and related processes and a plan for implementation before the conversion can begin. A consultant can be very helpful to plan, monitor, and assist in this process. While the specific changes for each firm will depend on their sector(s) of AEC activity, the general steps that need to be considered are similar and include the following (Sacks, Eastman, Lee, & Teicholz, 2018):

- Assign top-level management responsibility for developing a BIM adoption plan that covers all aspects of the firm's business and how the proposed changes will impact both internal departments and outside partners and clients.
- Create an internal team of key managers responsible for implementing the plan, with cost, time, and performance budgets to guide their performance.
- Allocate time and resources for education in BIM tools and practices and ensure that people at all levels are prepared.
- Start using the BIM system on one or two smaller (perhaps already completed) projects in parallel with existing technology and produce traditional documents from the building model. This will help reveal where there are deficits in the building objects, in output capabilities, in links to analysis programs, and so forth. It will also allow the firm to develop modeling standards and determine the quality of models and level of detail needed for different uses.
- Use initial results to educate and guide continued adoption of BIM software and additional staff training. Keep senior management apprised of progress, problems, insights, and so forth.

- Extend the use of BIM to new projects and begin working with outside members of the project teams in new collaborative approaches that allow early integration and sharing of knowledge using the building model.
- Continue to integrate BIM capabilities into additional aspects of the firm's functions and reflect these new business processes in contractual documents with clients and business partners.
- Periodically replan the BIM implementation process to reflect the benefits and problems observed thus far, and set new goals for performance, time, and cost. Continue to extend BIM-facilitated changes to new locations and functions within the firm.

1.1.4.4 Lack of National Standard

Construction industry or AEC industry depend mainly on standard and guidelines every country in the world has its own standard or following some type of guidelines to help the industry stakeholder to deliver their product sufficiently with computability of the environment of this country, some building guidelines in different countries have been developed to manage the use of BIM a long with the building standards, but no formal standard was established to generalize and standardize the use of BIM (Björk & Laakso, 2010).

1.1.4.5 High Cost of Application

Implementing BIM in a company require a lot of investment in the IT-infrastructure within this company, as BIM in most cases require a high performance computer to help in the graphic visualization and doing a proper render and as a higher level of detail of the model and the more data is added to the model the more sophisticated computer is need to process and analysis of this data, also the need of an educated IT-team to support the new software and to develop plug-ins to support more professional data exchange between the other company software. Besides the high initial cost of the software (Newton & Chileshe, 2012). The implementation of BIM is making a big difficulty for small companies in terms of cost to be implemented, and specially companies with no sophisticated IT-infrastructure (Ganah & Godfaurd Adjaie, 2014).

1.1.4.6 Lack of Skilled Personal

Skilled people to operate the BIM model is causing a big barrier towards the implementation of the BIM in the AEC industry. As a company is adopting a new BIM software. It has either one of two options one is educating the current staff how to use the new technology or going into hiring process and hire a new stuff who are expert in using this technology. The core of BIM is education and training to accelerate the adoption of the new technology, and not only focusing on the teaching of a specific software, but also delivering the idea of big BIM and teaching the core principal of BIM and the culture behind the adoption of this technology. Some studies were carried out on the role of BIM education of the students on the acceleration of the implementation of BIM in the industry and it showed positive relation between the education of the students and the implementation level of the BIM (Wu & Issa, 2014) .

1.1.4.7 Changes in Practice and Use of Information

The use of BIM encourages the integration of construction knowledge earlier in the design process. Integrated design-build firms capable of coordinating all phases of the design and incorporating construction knowledge from the outset will benefit the most. IPD contracting arrangements that require and facilitate good collaboration will provide greater advantages to owners when BIM is used. The most significant change that companies face when implementing BIM technology is intensively using a shared building model during design phases and a coordinated set of building models during construction and fabrication, as the basis of all work processes and for collaboration (Sacks, Eastman, Lee, & Teicholz, 2018).

1.2 Lean Construction

1.2.1 History of Lean Production

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

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

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

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

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

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

1.2.2 Principles of Lean Theory

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

There are five fundamental principles for lean thinking, which have to be followed step by step to gain the maximum benefit of the lean success (Aziz & Hafez, 2013):

1. **Specify Value:** Specify value from customer's own definition and needs and identify the value of activities, which generate value to the end product;
2. **Identify the Value Stream:** Identify the value stream by elimination of everything, which does not generate value to the end product. This means,

stop the production when something is going wrong and change it immediately. Processes which have to be avoided are miss production, overproduction (repeat production of the same type of product, etc.), storage of materials and unnecessary processes, transport of materials, movement of labor workforces and products, and finally production of products which does not live up to the wished standard of the customer as well as all kind of unnecessary waiting time;

3. **Flow:** Ensure that there is a continuous flow in the process and value chain by focusing on the entire supply chain. Focus has to be on the process and not at the end product. However, the flow will never get optimal until customer value is specified, and the value stream is identified;
4. **Pull:** Use pull in the production and construction process instead of push. This means produce exactly what the customer wants at the time the customer needs it and always prepared for changes made by customer. The idea is to reduce unnecessary production and to use the management tool ‘‘Just in Time’’; and
5. **Perfection:** Aims at the perfect solution and continuous improvements. Deliver a product which lives up to customer’s needs and expectations within the agreed time schedule and in a perfect condition without mistakes and defects.

Figure 2: Fundamental Principles of Lean Thinking

The only way to do so is by having a close communication with the customer/client as well as managers, and employees are between. Figure 3 summarizes examples of lean tools already used in job sites (Picchi & Granja, 2004).

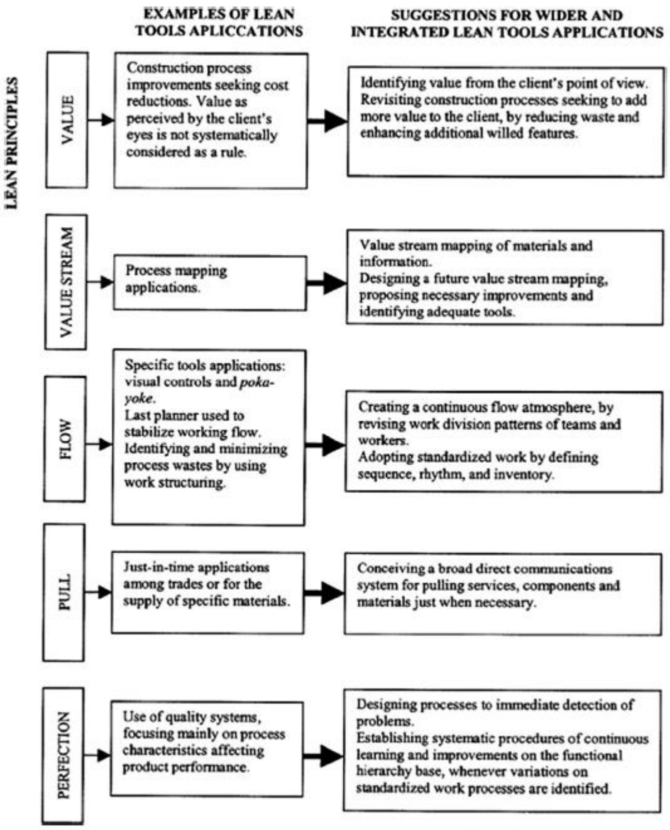

Figure 4 Examples of lean tools in construction implementation and suggestions [42].

Figure 3: Lean Tools in Construction Implementation and Suggestions

Koskela (1992) has summarized lean thinking into eleven principles which are:

1. Reduce the share of non-value adding activities (waste);
2. Increase output value through systematic consideration of customer requirements;
3. Reduce variability;
4. Reduce cycle times;
5. Simplify by minimizing the number of steps, parts and linkages;
6. Increase output flexibility;
7. Increase process transparency;

8. Focus control on the complete process;
9. Build continuous improvement into the process;
10. Balance flow improvement with conversion improvement; and
11. Benchmark.

There are fourteen principles organized in four categories: (1) Philosophy; (2) Process; (3) People and Partners; and (4) Problem Solving, as seen in figure 4 (Ballard & Kim, 2007).

The fourteen (14) management principles of the lean way are as follows (Aziz & Hafez, 2013):

1. Base decisions on long-term philosophy even at the expense of short-term financial goals (Philosophy);
2. Create continuous process flow to bring problems to the surface (Process);
3. Use ‘‘Pull’’ systems to avoid overproduction (Process);
4. Level out the workload (Process);
5. Build a culture of stopping to fix problems to get quality right the first time (Process);
6. Standardized tasks are the foundation for continuous improvement and employee empowerment (Process);
7. Use visual control so no problems are hidden (Process);
8. Use only reliable, thoroughly tested technology that serves people and processes (Process);
9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others (People and Partners);
10. Develop exceptional people and teams who follow your company’s philosophy (People and Partners);
11. Respect your extended network of partners and suppliers by challenging them and helping them improve (People and Partners);
12. Go and see for yourself to thoroughly understand the situation (Problem Solving);

13. Make decisions slowly by consensus, thoroughly considering all options; implement rapidly (Problem Solving); and
14. Become a learning organization through relentless reflection and continuous improvement (Problem Solving).

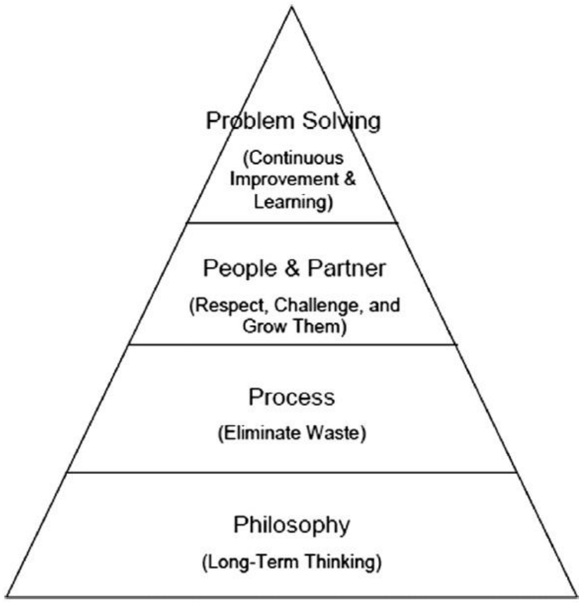

Figure 4: ''4P'' of the Lean Way

1.2.3 Techniques of Lean Theory

Lean construction is a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value (Koskala & et al, 2002). Lean Construction is using the same principles as lean production to reduce waste and increase the productivity and effectiveness in construction work. The most important determinants of construction are supposed to be workflow reliability and labor flow, but lean construction has changed the traditional view of the project as transformation and embraces the concept of flow and value generation. Similarly, it shares the same objectives of lean production, e.g., cycle time reduction, elimination of waste, and variability reduction. Continuous improvement pull production control, and continuous flow have been the direction for the implementation of lean construction. Lean construction is composed of the following techniques (Paez, 2005):

1. **Concurrent Engineering:** Concurrent engineering can be described as parallel execution of various tasks by multidisciplinary teams with the goal of obtaining most favorable products concerning functionality, quality, and productivity. Many enhancements can be accomplished by using concurrent engineering. Scheduling could be recovered by network analysis (CPM and PERT). Many other opportunities can be achieved through overlapping activities, splitting activities and reducing the transfer time between different activities. The important planning parameters for scheduling concurrent activities are lead time, quantity, and risk under ambiguity. Concurrent engineering is focusing on the team efforts; communication and information sharing are the keys for discovering new ideas. While partnering with subcontractors and suppliers can also be good changes regarding concurrent engineering, the success of lean production is depending on the involvement of all participants in the early stages of the design;
2. **Last Planner:** The last planner is the person or group of people responsible for production unit control, which means completion of individual tasks at the operational level. Last planner necessitates workflow control, ascertaining the stream of supply, design, and installation throughout production units. This can only be done by using look-ahead schedule, which determines the progression and rate of work. It carves up the master schedule into many packages, specifying the techniques of check capacity, execution, and establishes a stockpile of standing by work. The scope of look-ahead schedule ranges from 2 to 6 weeks and should be put in order by teamwork;
3. **Daily Huddle Meetings:** Daily huddle meetings provides a platform for the team members to share their views and to share what has been achieved, at the same time, discus problems they are facing during the production process;

4. **The Kanban System:** The strategy of Kanban is grounded on key components, i.e., marketplace, supplier Kanban, collection vehicle, satellite stores, and inventory management system. Market places are site warehouse that allocate different materials and small tools to the workers. Similarly, satellite stores are situated on site, where they get products from marketplaces. Collection vehicle collects materials from preferred suppliers to the operational site. Kanban use plastic bins as a signal to pull materials from suppliers to site, using the concept of Just in Time. Request forms are normally used as Kanban signals between marketplace and satellite stores. The system of Kanban starts normally with open doors, so that the site can pull materials from the supplier up to certain perimeters. Subsequently, the material requested from suppliers arrives at market, and products are later on picked from the stores, which are usually managed by recorder points;
5. **Plan Conditions and Work Environment in the Construction Industry (PCMAT):** The purpose is to introduce a plan of health and safety into the project execution, called ‘‘Plan of Condition and Work Environment.’’ These safety activities can generate limitations for scheduled tasks and that is why it should be embraced as a part of assignments. All safety practices are therefore amalgamated in short term planning, which can be analyzed through daily feedback from crew and subcontractors respectively;
6. **Quality Management Tools:** The fusion of quality management tools in the lean construction is based on the change from conformance-based quality to the quality at the source. A point system is normally employed to evaluate the execution of planned controls, which will help workers to follow planned controls instead of quality corrections; and
7. **Visual Inspection:** Visual inspection shows the uneven nature of the construction and leads to the application of visual tools for material, work and information flow, etc.

Identification of materials can accelerate repetitive processes and diminishes the risk of selecting wrong product. Progress charts and schedules can implement the dedication to the completion of tasks. Information and technology can also improve the communication between decision maker and executer and can accelerate the process as well. The Lean Construction Institute (Lean Construction Institute, 2004) described how current projects are to be managed and defines the project management as follows: (1) Determine client requirements and design to meet them; (2) Align design to quality, schedule, and budget limits; (3) Manage the project by breaking it into pieces, estimating duration and resource requirements for each piece, and then put the pieces in a logical order with Critical Path Method (CPM); (4) Assign or contract for each piece, give start notice and monitor each piece to assure it meets safety, quality, schedule and cost standards. Take action on negative variance from standards; (5) Coordinate using the master schedule and weekly meetings; (6) Cost may be reduced by productivity improvement; (7) Duration may be reduced by speeding each piece or changing logic; and (8) Quality and safety get better with inspection and enforcement.

1.2.4 Lean Project Delivery System

(Ballard G. , 2000) defined the lean project delivery system and concluded to divide it into 4 main phases:

1. Project Definition (initiation of the project and assigning the project target).
2. Lean Design (do the design from the conceptual formulation to the shop drawings).
3. Lean Supply (getting the design and define and supply the required means to make the projects from the raw material to the prefabricated elements).
4. Lean Assembly (assemble the material and putting it into sequence and manage it with the different resource to add value in the end to the output- this phase is also ended with the close out of the project).

In 2008 the same author added new phase to his model which is the Lean Use (include the use and the maintenance of the project which also could be named as FM) according also to the author experience a lot of clients fail to define the purpose of the projects instead they focusing on defining the means of the project (Ballard G. , The Lean Project Delivery System: An Update, 2008), which lead to enormous amount of the waste, by defining the purpose of the project that give the AEC (Architecture Engineer and Constructor) the room to enrich the project by their experience to make the project meet the requirements. Moreover, two models were added; production control model and work structure model, and all of that is put into a continues frame which link the end of the project with the beginning of the next one and named post-occupancy evaluation or lean loop to make sure of continuous improvement as show in figure 5.

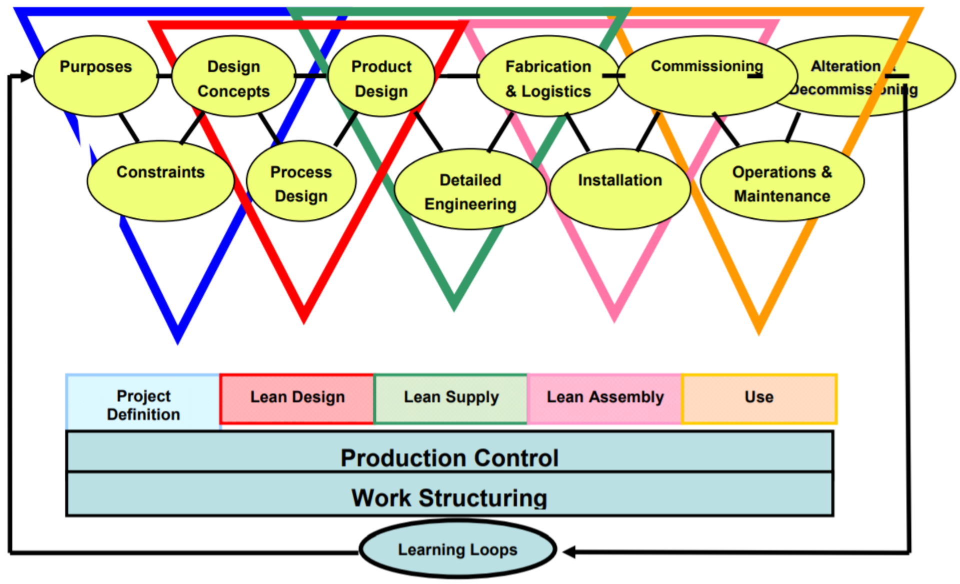

Figure 5: Lean Project Delivery System

Lean Project Delivery System (LPDS) is an interaction between the project and the production system and can be defined as a value generation process the stake holder are involved in the decision in different levels pull theory is used to synchronize the activity, feedback and continues improvement is done during the whole project.

1.2.4.1 Work Structuring

This term was orientated by Lean Construction Institute (LCI) to indicate the sequence of the work and to make sure that every resources are put in order to help in the development of the final product which mean everything from material to process are putting into a que to reach the final product. It is the very basic level of the process and is done by dividing the main project into work packages and assign this work package for a specialist group and how to monitor the progress in those group. Besides, how to connect this work package with the next one, and the buffer size between those work package how much? & where? Work structuring is not done once on the project life time but it is done for every phase of the indicated phases and more than one time in every phase (Ballard G. , The Lean Project Delivery System: An Update, 2008).

1.2.4.2 Production control

The main technique used in Lean Project Delivery System is Last Planner System (LPS) according to (LCI), last planner system is done by dividing the main project into pieces in a hierarchy mood that also will be discussed in the upcoming sections in detail. But production control in the lean culture not about the variance between the actual work and the planned work it is more about removing the abstract for the future work and trying to anticipate the risk related to each work package (Ballard G. , The Lean Project Delivery System: An Update, 2008).

1.2.4.3 Project definition

This is the early first phase of lean project delivery at this phase the project manager for the client will be the one who carry the responsibility for bridging the communication between the clients and the project stakeholders. In this phase a conceptual design formulation should be done, and the design of the production and the processes should also be discussed and having a deep knowledge about the design of the production and process in the next step.

Besides, an overview about the processes and production design for the whole project. Also, this stage contains the Cost Estimation, Project Duration, and the Target Quality (Ballard G. , The Lean Project Delivery System: An Update, 2008).

1.2.4.4 Lean Design

At this step the conceptual design which was the output of the prior phase will be the input for this stage, for this stage the decision should be done to meet the client's needs and deliver the maximum value to the customer, also the process design should be done a long side with the product design (while designing the product which is the facility in most cases the process to deliver this product should also be designed. As it was noticed to have a big impact on the reduction of the number of non-value-adding-activities. By the end of this phase design criteria should be developed and agreed by the deign-build team and the client (Ballard G. , The Lean Project Delivery System: An Update, 2008).

1.2.4.5 Lean Supply

This stage contains a detailed design of the elements which will be used of the delivery of the final product and also go farther for the prefabrication of those elements. And the processes which will be used to assemble them. Also, at this stage decision regarding the supply chain and the delivery of the material and the sub product will be taken. Also, the size of the inventories at the project, the buffer size between the tasks will be determined. The main purpose of this stage is to have a criteria of the supply chain and link it to the project production (Ballard G. , The Lean Project Delivery System: An Update, 2008).

1.2.4.6 Lean Assembly

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

1.2.5 Waste of Non-Value-Adding Work

The concept of waste (defined as any activity or consumption of resources that does not add value to the end customer) is key to Lean and the philosophy of continuous improvement. It is intertwined with the notion of respect for people in the company since it gives people ways of thinking, seeing and communicating with each other that all lead to additional value being created with fewer resources being consumed. When people in the organization have a shared vocabulary of waste, a shared understanding of the need to work continuously to minimize and eradicate each waste found, and a shared commitment not to blame individuals, they can begin to work collaboratively to improve. Each waste identified represents an opportunity to improve, thus increasing the efficiency and effectiveness of the organization as it creates value.

In order to help people identify the various forms of waste around them, Toyota identified three categories of waste, which have similar names in Japanese: Muda, Mura and Muri (Sacks, Korb, & Barak, Building Lean, Building BIM-Improving Construction the Tidhar Way, 2018).

Muda are the wastes inherent in the work processes. These are the traditional impediments to efficiency identified in the field of industrial engineering from as far back as Frank and Lillian Gilbreth and their studies of the wastes in bricklaying. Toyota identified seven canonical types of Muda, which further help focus the energies and the eyes of employees, which we discuss below.

Mura is the waste of unevenness. Any peak or trough in the workload represents either the overburdening of resources (this is the Muri that will be mentioned next) or lack of full resource utilization, and sometimes both. Slow and steady wins the race not only for the proverbial tortoise competing against the hare, but also in production; while constant, even demand and production are more boring than firefighting and racing to meet deadlines, they are much less prone to errors and waste. Construction is rife with examples of unevenness (like any industry, but writ even larger given the cyclical nature of the work of building a building), and all of the unevenness represents waste and opportunities for improvement.

Muri is the waste of overburden. Any resource, be it human or otherwise, has a limit to how much it can deal with at one time. It may be possible to exceed those limits for short periods of time, but long term, the behavior is unsustainable. Machines begin to break down and people begin succumbing to stress. Overworking does not demonstrate respect for people, and it leads to increased errors, which in turn cause defects.

Muri and Mura are often given less emphasis than Muda in all its forms, but they are no less important and no less wasteful.

The Types of Muda

Taiichi Ohno identified seven main types of process wastes that can occur. Just like the concept of waste in general, the point of this typology is to help people learn to see as they look for examples of each type. There may be examples of waste that do not fit neatly into any of these categories, and more often than not there is overlap between the types (or one may lead naturally to another).

The seven types can be remembered in the mnemonic TIMWOOD, as follows:

Transportation: the waste of moving raw materials around on their journey to becoming finished products. In practice, it is infrequent that value is added while the material is being moved (ready-mixed concrete is a wonderful exception that strongly illustrates the rule), which means that almost all movements of materials are waste. One way to track the more egregious wastes of transportation is to create what's called a "spaghetti map" – trace the path that the material takes on its entire journey through the process. This can often produce eye-opening results.

Inventory: any material or products that are sitting by themselves, not being worked upon, are by definition not having value added to them. And this is what inventory represents: a stockpile of waste. In financial terms, inventory must be purchased (requiring an outlay of cash), but until it is sold as a finished product, the purchase price is not recovered. Thus, a company that has a large inventory has much more cash tied up than one that has managed to reduce its inventory, and cash flow is a primary concern of most construction companies. Improved cash flow is one of the major benefits for companies that begin seriously implementing Lean. Inventory is one of the easiest wastes to find since it stands out to any observer who has been sensitized to see it as waste. In construction, all of the piles of raw materials are clearly inventory, but also any unfinished building, unit or apartment is also a form of inventory. If the project has repeating sub-units (like an apartment building), then the number of units being worked on at any point in time can be considered a form of WIP inventory.

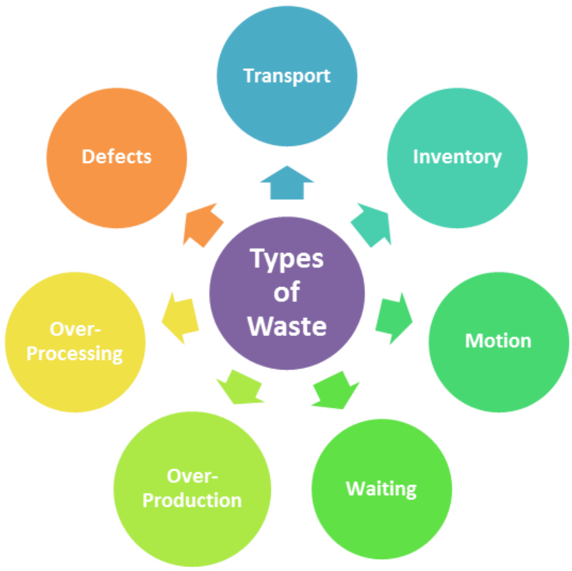

Figure 6: The Types of Muda Wastes

Motion: the waste of movement of workers around the job site that does not add value. This operates at both a macro level (for example, if the worker repeatedly has to walk from one area to another to retrieve tools or materials) and at a micro level (including ergonomic issues like having to reach up too high to retrieve a product from a shelf). Transportation is about materials while motion is about people, but both have to do with moving around without adding value. Here too, spaghetti maps can be helpful aids; one organization found that in the course of a typical shift, a factory worker was walking over three miles to fetch tools and materials from different parts of the building.

Waiting: if a person or machine has been employed to perform a job but is prevented from doing so since not all of the prerequisites are in place (i.e. the raw materials have not arrived, equipment has broken down, a quality problem is being investigated upstream), then that person's or machine's time is wasted.

Overproduction: performing a task before it is required by the next step in the process and/or processing a larger quantity than is required by that next step in the process. Taiichi Ohno cited overproduction as the worst waste of all, since it is overproduction that causes inventory. Inventory then must be stored somewhere, which requires transporting the material to the storage location. When the workers come to retrieve it, they incur wasted motion. Also, while the inventory is being built up, there is a greater possibility that defects will go unnoticed by the downstream processes, which means that more will have to be reworked or discarded once the defect is eventually unearthed. Not to mention that the inventory can be damaged by external factors while it is waiting around (precipitation, wayward forklifts, changes in demand). All of this arises because of overproduction. The concept of overproduction being a waste flies in the face of traditional efficiency thinking and requires a paradigm shift to fully appreciate. Traditionally, each step in the process tries to pump out product as fast as it can, with no regard to the readiness of the next step in the process to accept the output. If any latter process is not ready, then technically any production done by the former process is overproduction, which is a waste.

Over-processing: putting additional effort into a product beyond what is desired and valued by the customer. Sometimes companies try to outdo themselves in terms of the quality and number of features that their product offers. But if those features and quality are not what the customer requires (and not what he or she would want to pay for), then they are waste.

Defects: any quality issues that lead to a product being discarded. In addition, beyond the part that gets thrown in the trash, all the processing and transportation steps that led up to the point where the item is rejected are implicitly also wasted. They too are all being thrown in the trash. The waste of rework is included in this category. Rework does not result in the whole product being thrown out, but it does require handling and processing the product much more than required by the customer.

1.3 Lean and BIM Together

Lean Construction is a management paradigm that tends to disrupt traditional patterns of work. It can be implemented without any technology, but technological tools can support its implementation. BIM is first and foremost a technology, but it is not only a technology. Its successful implementation is entirely dependent on introducing BIM appropriate workflows that are different from traditional workflows (Sacks, Korb, & Barak, Building Lean, Building BIM-Improving Construction the Tidhar Way, 2018).

Introducing two novel systems simultaneously could cause disruption and failure of both efforts, posing a serious threat to the health of any construction company, if they are not compatible. Are the process changes required for BIM and Lean Construction compatible? This is a necessary (although not sufficient) condition for simultaneous implementation. The question has been researched extensively, and the answer is that for the most part they are compatible, although some points of friction have been identified.

In a 2010 article entitled "The Interaction of Lean and Building Information Modelling in Construction", the authors analyzed the possible interactions between 24 Lean Construction principles and 18 BIM functionalities (Sacks & et al, Interaction of Lean and Building Information Modeling in Construction, 2010). By examining many examples from construction case studies, they identified 54 points of direct interaction, of which 50 were positive (mutually reinforcing) interactions and just 4 were negative. For example, when designers collaborate closely using BIM (functionalities 9 and 10), the result is a significant reduction in the cycle time needed for each design iteration (principle C; these are interactions 23 and 24 in table 1). However, the principle of reducing inventory (D) can be violated if planners generate large numbers of construction plan alternatives just because it is easy to do so using the power of the computer with BIM technology (interaction 29 in table 1).

Stage	*Functionality*
Design	Visualization of form
	Aesthetic and functional evaluation (1)
	Rapid generation of multiple design alternatives (2)
	Reuse of model data for predictive analyses
	Predictive analysis of performance (3)
	Automated cost estimation (4)
	Evaluation of conformance to programme/client value (5)
	Maintenance of information and design model integrity
	Single information source (6)
	Automated clash checking (7)
	Automated generation of drawings and documents (8)
	Design and fabrication detailing
	Collaboration in design and construction
	Multiuser editing of a single discipline model (9)
	Multiuser viewing of merged or separate multidiscipline models (10)
	Preconstruction and construction
	Rapid generation and evaluation of construction plan alternatives
	Automated generation of construction tasks (11)
	Construction process simulation (12)
	4D visualization of construction schedules (13)
	Online/electronic object-based communication
	Visualizations of process status (14)
	Online communication of product and process information (15)
	Computer-controlled fabrication (16)
	Integration with project partner supply chain databases (17)
	Provision of context for status data collection on site/off site (18)

Source: Sacks et al. (2010). Reproduced with permission from ASCE.

Table 1: BIM Functionality

Area	Principle and means
Flow process	**Reduce variability** Get quality right the first time (reduce product variability) (A) Focus on improving upstream flow variability (reduce production variability) (B)
	Reduce cycle times Reduce production cycle durations (C) Reduce inventory (D)
	Reduce batch sizes (strive for single piece flow) (E)
	Increase flexibility Reduce changeover times (F) Use multi-skilled teams (G)
	Select an appropriate production control approach Use pull systems (H) Level the production (I)
	Standardize (J)
	Institute continuous improvement (K)
	Use visual management Visualize production methods (L) Visualize production process (M)
	Design the production system for flow and value Simplify (N) Use parallel processing (O) Use only reliable technology (P) Ensure the capability of the production system (Q)
Value generation process	**Ensure comprehensive requirements capture (R)** **Focus on concept selection (S)** **Ensure requirement flow down (T)** **Verify and validate (U)**
Problem solving	**Go and see for yourself (V)** **Decide by consensus, consider all options (W)**
Developing partners	**Cultivate an extended network of partners (X)**

Source: Sacks et al. (2010). Reproduced with permission from ASCE.

Table 2: Lean Construction Principles

The authors concluded that implementing BIM and Lean Construction simultaneously was not only possible, but indeed highly recommended, because many BIM functionalities improved the flow of design, planning, supply chain and construction processes, a key part of Lean. Thus, to successfully integrate the work processes that will replace traditional ones in any given construction company, those guiding the effort should be aware of these interactions, and consciously plan to amplify the positive ones while taking precautions not to fall into the traps set by the negative ones.

With the advancements made through BIM, its implementation and application, it has shown that it can be used in aiding the achievement of Lean construction objectives. The objectives that Lean Construction has like waste elimination, increase in value to client and team collaboration. All of these objectives have been obtained when BIM is applied. By the use of 4D, BIM schedules were made to look ahead and simulate possible causes of bottlenecks and collisions that may occur in the teams' coordination or logistics and prevent them before they happened. Another observation was the detection of clashes acted as a warning system that ensured that wastages were minimal (Gerber & et al, 2010). When BIM application is used together with collaborative planning then the effectiveness in eliminating nonvalue task is possible (Mattsson & Rodny, 2013).

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

Also, it has proven that when production theory and lean principles were applied together with the information technology, the uncertainty through the whole process was reduced which contributes to reduction in variability. This makes it easier for the client's requirements to be meet hence giving value from the supplier to client (Rischmoller & et al, 2006).

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

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

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

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

Chapter 2

Architectural, Engineering and Construction (AEC) Industry

2.1 Design-Bid-Build Project Delivery System

Lim and Alum (1995) documented the prevalence of low productivity in the construction industry. The situation has not changed for the better. Low productivity is still prevalent in the 21st century (Ying, 2005; Gao and Low, 2014). There are several studies documenting the role of fragmentation among construction professionals (Dulaimi et al., 2002; Xue et al., 2007; Howard et al., 1989). There are studies suggesting that while fragmentation is a cause of low construction productivity, it is not the root-cause. These studies suggested that the root-cause of low productivity is in the social structure of the construction industry (Hindle, 1997; Latham, 1994; Hindle, 2004). Hindle (2004) likened the social-structure of the construction industry to that of British Colonial era. According to Hindle (2004), in a British Colonial social structure there is:

‘‘A ruling class with high status supported by government; in a structure that embodied elitism and a rigid hierarchy; governance over a body of people who were not allowed to participate and who were thought of as ‘second class’ citizens”.

Relating this statement to the construction industry social structure, the design consultants, especially architect, have high status supported by the client (developer or owner) governance over contractor and sub-contractors who usually do not participate during the design stage and thought of as ‘‘second class” professionals. Even when client has a contract with a contractor, architect administers control over the implementation of that contract on behalf of the client (Cox and Thompson, 1998). This social structure influences the contracting system and resulting fragmentation in the construction industry (Ball, 1988; Lewis and Cheetham, 1993).

2.1.1 Process of DBB

Design-Bid-Build (DBB) is a well-known contracting method in the construction industry. The client issues two contracts – one contract for the architect while the other contract is for the contractor. The architect designs the building and invites consulting engineers, like mechanical, electrical and plumbing (MEP) engineers, fire protection engineer, structure engineer, and other professionals relevant to the development of the design, construction drawings, and specifications needed for the bidding process. The client invites several contractors to bid for the project. The owner then awards the construction contract to the contractor with the lowest bid (Waara & Brochner, 2006).

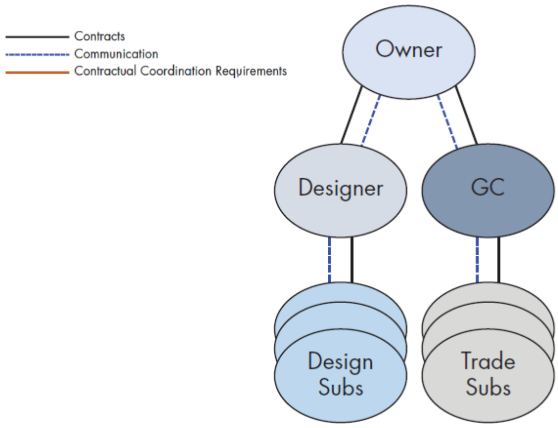

Figure 7: Schematic Diagram of Design-Bid-Build (DBB)

The adoption of BIM, a knowledge management strategy, at the design stage would enhance the success of the integrated and iterative design process in delivering the required sustainable building performance (Sanguinetti & et al, 2012). The selected contractor could later use the generated BIM design model and associated information produced during the design stage to produce every details, including shop drawings, building components fabrication, schedule and cost estimation, needed at the construction stage (Clevenger & Khan, 2014) (Kim & et al., 2013).

However, there is no avenue for communication between the chosen contractor and the architects and consulting engineers during the design stage. Thus, the potential benefits of BIM in ensuring constructability of the design at the design stage will be limited because of no input from the contractor. Depending on the complexity and severity of the constructability issues raised by the contractor at the construction phase, architects may need to call back all the engineers and relevant professionals involved at the design stage. Limited or no integration of design (knowledge) of architect, engineers and other professionals involved at the design stage – a situation that is very common in the building industry – would further increase the severity of constructability issues raised by the contractor (Hallowell & Toole, 2009). The time taken by the contractor to list all the identified constructability issues and for the designers and relevant professionals to resolve them would determine the cost implications and the extent of delay in delivering the sustainable building value. If professionalism of the contractor is valued in the same elitism and hierarchy as architect and other consulting engineers delivering the sustainable building performance value, contractor will be allowed to take part at the design stage to give valued advice and opinion on design constructability.

2.1.2 Advantages of DBB

- The architecture, engineering, and construction (AEC) industry is familiar with this method.
- It is a straightforward competition. If you’re the low bid, you get the job.
- It doesn’t have legal barriers. This method is accepted in every state and can be used in all markets, including public and federal, provided there are multiple bids.
- The owner keeps a traditional relationship with the architect and has complete control over the design (Hardin & McCool, 2015).

2.1.3 Challenges of DBB

- There is limited or no communication between the designers and the contractors during the design phase.
- The lack of communication typically leads to cost overruns due to estimates (cost tracking) not being done throughout the design.
- The RFI and change order process can create friction between the architect/engineers and the contractor, because the gaps or errors have to be justified to the owner who pays for the issues.
- There may be increased litigation due to the lack of collaboration.
- It is a slower delivery method, since the full construction drawings must be completed prior to bid and construction (Hardin & McCool, 2015).

2.2 Documented Inefficiencies of Construction Industry

2.2.1 Construction Industry Labor Productivity

Extra costs associated with traditional design and construction practices have been documented through various research studies. More recently compiled data, shown in figure 8, shows that the trend of increasingly weaker construction productivity when compared with manufacturing has continued, but it also shows the gap between off-site and on-site construction activities. It is clear that fabrication off-site is more productive than construction on-site.

During the 45-year-long period covered, the productivity of the manufacturing industries has more than doubled. Meanwhile, the productivity of construction work performed on-site is relatively unchanged.

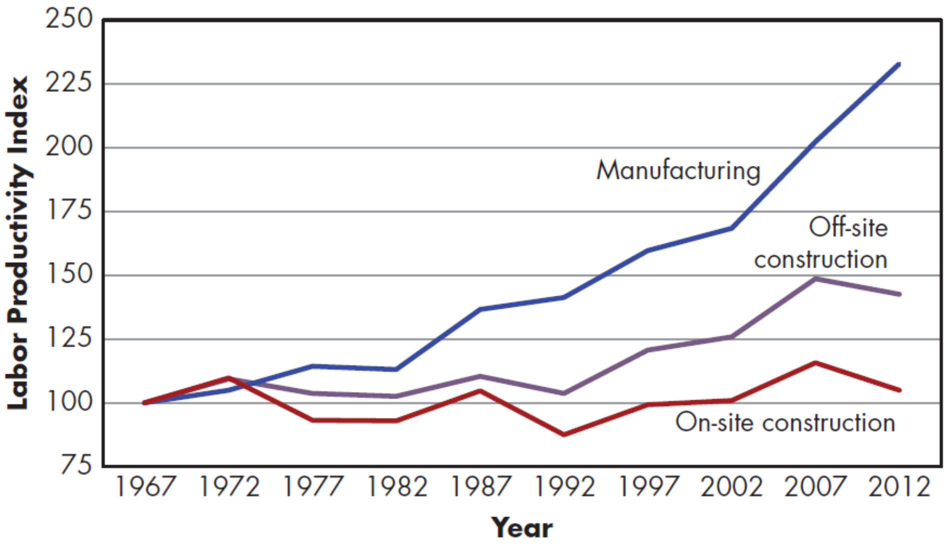

Figure 8: Indices of Labor Productivity for Manufacturing and Construction Trades 1967–2015.

While the reasons for the apparent decrease in construction productivity are not completely understood, the statistics are dramatic and point at significant structural impediments within the construction industry. It is clear that efficiencies achieved in the manufacturing industry through automation, the use of information systems, better supply chain management, and improved collaboration tools, have not yet been achieved in field construction. Possible reasons for this include:

- The adoption of new and improved business practices within both design and construction has been noticeably slow and limited primarily to larger firms. In addition, the introduction of new technologies has been fragmented. Often, it remains necessary to revert to paper or 2D CAD drawings so that all members of a project team are able to communicate with one another and to keep the pool of potential contractors and subcontractors bidding on a project sufficiently large. Almost all local authorities still require paper submittals for construction permit reviews. For these reasons, paper use maintains a strong grip on the industry.
- Whereas manufacturers often have long-term agreements and collaborate in agreed-upon ways with the same partners, construction projects typically

involve different partners working together for a period of time and then dispersing. As a result, there are few or no opportunities to realize improvements over time through applied learning. Rather, each partner acts to protect him- or herself from potential disputes that could lead to legal difficulties by relying on antiquated and time-consuming processes that make it difficult or impossible to implement resolutions quickly and efficiently. Of course, this translates to higher cost and time expenditures.

- Another possible cause for the construction industry's stagnant productivity is that on-site construction has not benefited significantly from automation. The lower cost associated with these workers may have discouraged efforts to replace field labor with automated (or off-site) solutions, although automation in construction is less dependent on the cost of labor than on technological barriers to automation, such as the nature of field work environments and the relatively high setup costs for use of automated machinery.

2.2.2 Cost of Construction Industry Inefficiency

The National Institute of Standards and Technology (NIST) performed a study of the additional cost incurred by building owners as a result of inadequate interoperability (Gallaher et al., 2004). The study involved both the exchange and the management of information, in which individual systems were unable to access and use information imported from other systems. In the construction industry, incompatibility between systems often prevents members of the project team from sharing information rapidly and accurately; it is the cause of numerous problems, including added costs. Table 3 shows the breakdown of these costs and to which stakeholder they were applied.

In the NIST study, the cost of inadequate interoperability was calculated by comparing current business activities and costs with hypothetical scenarios in which there was seamless information flow and no redundant data entry. NIST determined that the following costs resulted from inadequate interoperability:

- Avoidance (redundant computer systems, inefficient business process management, redundant IT support staffing)
- Mitigation (manual reentry of data, request for information management)
- Delay (costs for idle employees and other resources)

Stakeholder Group	Planning, Engineering, Design Phase	Construction Phase	O&M Phase	Total Added Cost
Architects and Engineers	$1,007.2	$147.0	$15.7	$1,169.8
General Contractors	$485.9	$1,265.3	$50.4	$1,801.6
Special Contractors and Suppliers	$442.4	$1,762.2		$2,204.6
Owners and Operators	$722.8	$898.0	$9,027.2	$10,648.0
Total	**$2,658.3**	**$4,072.4**	**$9,093.3**	**$15,824.0**
Applicable sf in 2002	1.1 billion	1.1 billion	39 billion	n/a
Added cost/sf	**$2.42/sf**	**$3.70/sf**	**$0.23**	**n/a**

Source: Table 6.1 NIST study (Gallaher et al., 2004).

Table 3: Additional Costs of Inadequate Interoperability in the Construction Industry, 2002

Of these costs, roughly 68% were incurred by building owners and operators. These estimates are speculative, due to the impossibility of providing accurate data. They are, however, significant and worthy of serious consideration and effort to reduce or avoid them as much as possible. Widespread adoption of BIM and the use of a comprehensive digital model throughout the lifecycle of a building would be a step in the right direction to eliminate such costs resulting from the inadequate interoperability of data.

2.3 Traditional Design Management

2.3.1 2D CAD Design approach

Architectural and engineering design is a task for large teams consisting of specialists, such as architects, constructors, installation engineers, quantity surveyors, project managers. For many centuries the basis of the projects was (and are) 2D drawings (plans, sections, elevations) of designed building in a symbolic manner, in accordance with the principles accepted by all participants in this process. Usually the architectural concept is fundamentally different from the final design and structural design. Architects mainly use sketches of bodies (3D elements shown in perspective) whereas civil engineers - plans or details drawings. Another source of confusions or mistakes are two types of plans: architectural projection shows what is below the cut surface, which is usually located at a height of 1m above the designed floor, as an architect is interested in the layout of the designed story. In contrast, a building (construction) plan shows what is under the ceiling of the floor considered by architect, since constructor is interested in the substructure supporting the floor considered by architect (Czmoch & Pekala, 2014).

In the classical method of designing each of the specialists work on separate industry drawings (prepared on tracing papers) with only those elements for which they are responsible. Tracing papers produced by specialists are imposed on each other during the coordination meeting to check the compatibility of the project. CAD systems modernized the process. Instead of tracing papers the separate layers in the CAD program are used by each of the specialists. However, designer works in CAD on plans of the same building and the interdisciplinary collisions (e.g. structure-installation) are inevitable. The coordination meeting and correspondence are devoted mainly to solve the conflicts. Use of the CAD systems makes this process easier although it is time consuming and not always successful. When on one layer with installation something is changed then quite often it is not on 2D drawings not only with plans, but also with cross-sections or elevations, which should be changed both in architectural and structural design.

In parallel with CAD software CAE systems have been developed to support the calculation of the structure. Special programs have been developed for installations. Nowadays functionality of available CAE programs is very high starting from simple programs for static or dynamic analysis of specific elements or structure, including checking the requirements specified by standards. Complex calculation systems collaborating with CAD/BIM systems are developed steadily. They allow for comprehensive modelling of the structure; the load patterns combination module supports thousands of different variants. Final results of analysis can be easily transferred to CAD/BIM systems in order to adjust the 2D/3D model and produce structural drawings (dimensioning and reinforcement drawings, detailed design of steel connections etc.).

2.3.2 Inefficiencies of 2D CAD Approach

2.3.2.1 Communication Related Problems

Acquiring required input data on time is an essential prerequisite for an uninterrupted design process. If the required data is missing, the design process is disturbed. This was one of the most essential problems that affected the design process. It partially results from the fact that design disciplines do not understand each other's processes and requirements and thus cannot recognize, if input data required from them is critical for the design process to continue. The problem was also linked to the observation that it takes too long time to receive an answer to an email. Before the answer is received, the design process cannot proceed.

Collaboration between designers has not worked. This resulted from the fact, that designers were not familiar with each other. Organizing a design group that works effectively together is a challenging task for the design management. Design disciplines worked in separate offices. Therefore, no face-to-face communication was practiced in daily work. Collaboration between parties is needed, especially in coordinating change management situations. The architect model is not always updated according to a structural model. This leads to problems because building services design uses the architect model as an input data and geometry of structures is critical for their design (Tauriainen & et al,, 2016).

Researches have shown the productivity loss of 22.5% in the design offices (in 2D design). In order to change this situation, the integration of information starting from the design can become a viable tool. Also, this can be considered as an essential mechanism to decrease mistakes, increase teamwork, efficiency gain and speed, with a subsequent improvement in quality and productivity (Jacoski & Lamberts, 2007).

The transfer of information between the design participants is inconsistent; there is usually only exchange of information in part of the design team. A lot of information is lost, and in some cases, it is generated in contradiction and in other situations unnecessarily duplicated. Due to these facts, the design tends to be delayed and more expensive than necessary (Jacoski & Lamberts, 2007).

2.3.2.2 Instruction Related Problems

Proper modeling instructions were not used. These instructions should be created by the client or the owner of the project in cooperation with design disciplines at the beginning of the project before the modeling process has been initiated and they have to be presented in the project initiating meeting. First, instructions should define how modeling should be done. This includes the software versions, file formats, how often the model is shared, location of origin and other issues related to the actual creation of the model. Second, instructions should define what is to be included in the models. In the projects, only the necessary modeling objects were highlighted in the instructions. Third, special process related instructions should be published and followed carefully. These instructions include, e.g., void provision instructions and a list of critical structures.

It is most likely that the use of comprehensive instructions would improve the cooperation and design process. Importance of active project management and design supervision is essential part of successful void provision and this also includes the utilization of instructions. A design manager together with a designer responsible for the void provision phase have to make sure that each designer is aware of the importance of using prearranged work methods, which include the use of instructions. Also, structural designers have to publish instructions well in advance so that building services designers can take advantage of them (Tauriainen & et al,, 2016).

2.4 Lean-BIM-Based Design Management

Use of BIM and lean design management can lead to an increased value realization for the customer. The content of design work can be visualized and design tasks that do not create value can be identified and removed. At the same time, value adding tasks can be improved. Also the number of design cycles and design errors can be decreased which further leads to a faster, smoother and more economical construction process (Merton, Fiske, & Kendall, 1990).

BIM greatly reduces design conflicts by relying on one information source and enabling clash checking. It has enabled a better visualization of form and evaluation of function. Other improvements include easier generation of design alternatives, better maintenance of information and design model integrity including reliance on a single source of information and active clash detection. Design requirements are also easier to define, and information flows are improved. As a result of reduced cycle time of drawing production, the conceptual design phase can be extended (Sacks, Eastman, Lee, & Teicholz, 2018). BIM has succeeded in changing work processes and removing much of this waste.

The architect, implements BIM to produce architectural drawings, followed by engineers producing structural or energy data management and contractor develop coordination model of the building. Concept design does not only provides a framework of design in terms of its structure, spatial layout, and environmental condition, but also the cost estimates, building practices and the aesthetic considerations as well (Sacks, Eastman, Lee, & Teicholz, 2018). Furthermore, BIM does provide several tools to assist designers that involve in design phase, which is Autodesk Revit that composed of Revit Architectural, Revit Structural, Revit MEP as well as Tekla that currently practices in construction industry (Ahmad Latiffi & et al, 2013). In brief, there are various types of BIM tools available for designers to develop project designs. However, it is not necessarily for companies or firms to practice only one type of BIM tools for their designers. This is due to the differences involving the design team in terms of skills, preferences and desired outputs (Mohd Nor & Grant, 2014). Hence, monitoring is needed to ensure the designers achieves what has been expected from them in term of work quality and productivity if the whole team design practices different BIM tools (Kasim & et al, 2017).

Lean in its simplest form means eliminating waste from every stage of a work process and at the same time producing added value to the customer by completing value adding functions as effectively and quickly as possible (Dave, Koskela, Kiviniemi, Tzortzopoulos Fazenda, & Owen, 2013) (O'Connor & Swain, 2013). The use of last planner system has spread from construction management to design management. The purpose is to maximize the productivity of labor, resources and materials and in addition, improve the managing of issues related to construction project variability and work-flow smoothness. Using last planner system in design and design management can lead to improvement in project transparency through schedules, design structure matrices and percent plan complete (Cremona, 2013).

Lean principles are used to generate value for the customer. The essential idea in target value design is to make clients value a driver of design. These can be specific design criteria, cost, schedule or constructability. Choosing this driver of design can lead to the reduction of waste and fulfilling or exceeding of client’s expectations (Zimina, Ballard, & Pasquire, 2012). There is evidence that projects are often completed as much as 19 percent below market costs when using target value design. The value is produced in the cooperation between project parties (Dave, Koskela, Kiviniemi, Tzortzopoulos Fazenda, & Owen, 2013).

Collaboration between parties could be facilitated using ideas of big room and Knotworking. The basic idea of big room is that different designers work side by side in the same location. This enables more effective information sharing between them when compared with working different locations. Big room decreases the latency of decision making. Information can be asked face to face instead of using remote communication tools or waiting for proper meetings. This leads to a shortening of overall design time by decreasing the duration of single design tasks. Big room is best suited for large construction projects where designers can work only on one project at the time, but sometimes the projects are not so large for this reason the altered form of big room, which is called knotworking has been created. The basic idea of knotworking is that designers meet at the same location in the planned or spontaneous critical points of the project when cooperation benefits the most. These knotworking points usually last for a few days after, which designers can go back to their own offices and continue to work on their respective projects (Kerosuo, BIM-Based Collaboration Across Organizational and Disciplinary Boundaries Through Knotworking, 2015) (Kerosuo, Mäki, & Korpela, Knotworking – a novel BIM-based collaboration practice in building design projects, 2013).

Chapter 3

Methodology

3.1 Research Question and Objectives

This research aims at understanding and comparing the information flow in the design phases of both traditional 2D CAD and BIM-based design projects under traditional project delivery (DBB contract type). The specific aims identified in this study include:

1. Understanding how the information flows on traditional 2D CAD projects in the design phases of Design-Bid-Build delivery system is,
2. Identifying the types of wastes and inefficiencies in traditional 2D CAD design projects,
3. How BIM and LEAN can impact on design phase information flow of DBB projects and propose the process improvements with respect to the 2D CAD approach.

3.2 Research Methodology

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

1. Conducting a literature review on Architectural Engineering and Construction (AEC) Industry, Design-Bid-Build as a traditional project delivery system, Building Information Modeling (BIM), Lean philosophy, BIM and LEAN interoperability and previous research worked on information flow and workflows of both traditional 2D CAD and BIM-based design phases,

2. Open contextual interviews were carried out informally with experienced engineers and design professionals to capture the opinions on the information exchange and flow between the design participants in traditional 2D CAD as a current dominant design approach and BIM-based design as growing and future of the construction projects, and
3. Using the Value Stream Mapping (VSM) as the Lean tool to model the information flows of two design approaches and investigate how BIM can eliminate the wastes and add value to DBB 2D CAD design and make it leaner.

3.3 Scope and Limitations

The research is limited to the use of BIM in design phase of Design-Bid-Build projects and how it will impact on information flows between different parties of the project.

Chapter 4

Results and Discussion

4.1 Value Stream Mapping

One of the most powerful tools in Lean is VSM, which is basically a pencil-and paper technique. The value stream map graphically represents the flow of materials and information through the process as value is added to the product (MHRA, 2007).

A value stream mapping process can be split into four steps, each with its own objective. The following: Preparation, Current state, Future state and Planning & Implementation, see figure 9. (Locher, 2008).

Mapping the process helps give a clear picture of the design phase and assists in the identification of hidden problems and existing waste. Using VSM, make it possible to assess and optimize the entire process of design management and information flow and not only individual tasks. VSM also creates a map by which to identify the future-state of the system, called the future-state map, which provides a picture of the Lean transformation process. The required improvements to the current state and an overall concept of how the design should ideally works are identified and presented in a future-state value map (Marvel & Standridge, 2009).

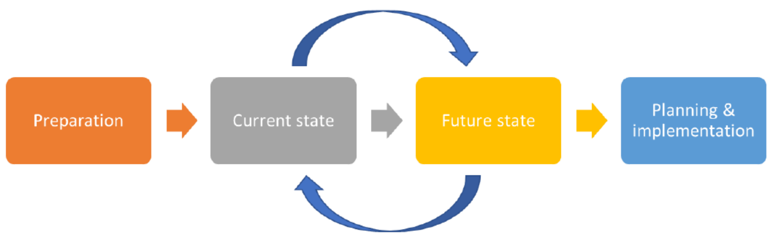

Figure 9: Value Stream Mapping Process

4.2 Information Flow in Traditional 2D and BIM-Based Design

BIM can be used as a noun to mean a building information model, an n-dimensional model which is a compilation of building information of interrelated objects. One might confuse a BIM to a regular 3D model; the latter however does not contain any smart information as it is just a 3D representation tool. Moreover, BIM can be used as "Building Information Modeling" referring to the process of using the provided model and building information to simulate and help perform real activities involved in the project (Sacks, Eastman, Lee, & Teicholz, 2018). The strength of BIM, which many users have not yet realized as they think of BIM as just a "tool or software" rather than a "process", lies in the collaboration that BIM allows and requires between the stakeholders throughout the project's life cycle (Azhar S. , 2011). The major contributor for the waste of information on projects is ineffective information sharing and flow. On traditional projects, the information flow between the players and project stages is jumbled. However, on BIM-based projects, the interaction is more flexible and overlapped where information is aggregated and shared transparently between the different users. BIM streams information sharing of proposed designs that enable different design teams to more easily collaborate using a 'live' version of the building model instead of working in silos and snapshots. This way users can assess the impact of changes more realistically on the overall design and in real-time rather than experience late obsolete data hand-offs, back flows, and rework (Al Hattab & Hamzeh, 2013).

In the lean environment, it has become generally recognized that planning and managing the design process can improve project efficiency and client satisfaction. This chapter aims at providing a comprehensive information flow process modeling of the design phase of both traditional 2D CAD and BIM-based projects. In addition, it provides a thorough comparison of both models to highlight problems in the traditional 2D CAD design processes and the benefits of BIM use making the design phase lean.

4.3 Current State (Traditional 2D Design Phase)

The traditional 2D CAD design phase information flow was modeled in cross-functional (swim-lane) diagrams (Al Hattab & Hamzeh, 2013). The choice of swim-lane diagram is for the fact that it helps present three things simultaneously: (1) information flow, (2) clear information exchange between the different participants, and (3) data deliverables resulting from each design process. The swim-lane diagram shown in figure 10 (Al Hattab & Hamzeh, 2013) is divided horizontally into three lanes (architect/designer, structural/civil engineer, and MEP engineer). Vertically, the diagram is divided into four phases. The first phase is the conceptual design phase, followed by review and iterations (rework) period when the conceptual design phase tentatively ends, and once the review period and any rework has been performed and accepted by the owner, the schematic design phase is triggered. In a similar fashion, it is followed by a review and iterations period once the schematic design phase tentatively ends.

After receiving the approval of the owner, the design teams can then proceed to the detailed design phase which will be more stream-lined and straightforward. The architects start by developing the design concept and then generate information deliverables like preliminary massing and orientations of the project. These deliverables are collected as documents, and after the architect concept design ends tentatively, they are then passed on to the structural/ civil engineers who have been waiting to receive these documents and experience delays and idle time. Similarly, the structural/ civil engineers proceed with developing their concept design and generate information deliverables. Meanwhile, the MEP engineers after also waiting to receive the data deliverables from the architects, start developing their concept design as well. Only after the teams have finalized their preliminary concept designs, silos of information documents can then share in iterative feedback loops between the different teams to perform the necessary adjustments. Traditionally, the teams must submit their information deliverables to the architects and owners for their decision, which results in either the acceptance (with comments) or rejection of the design

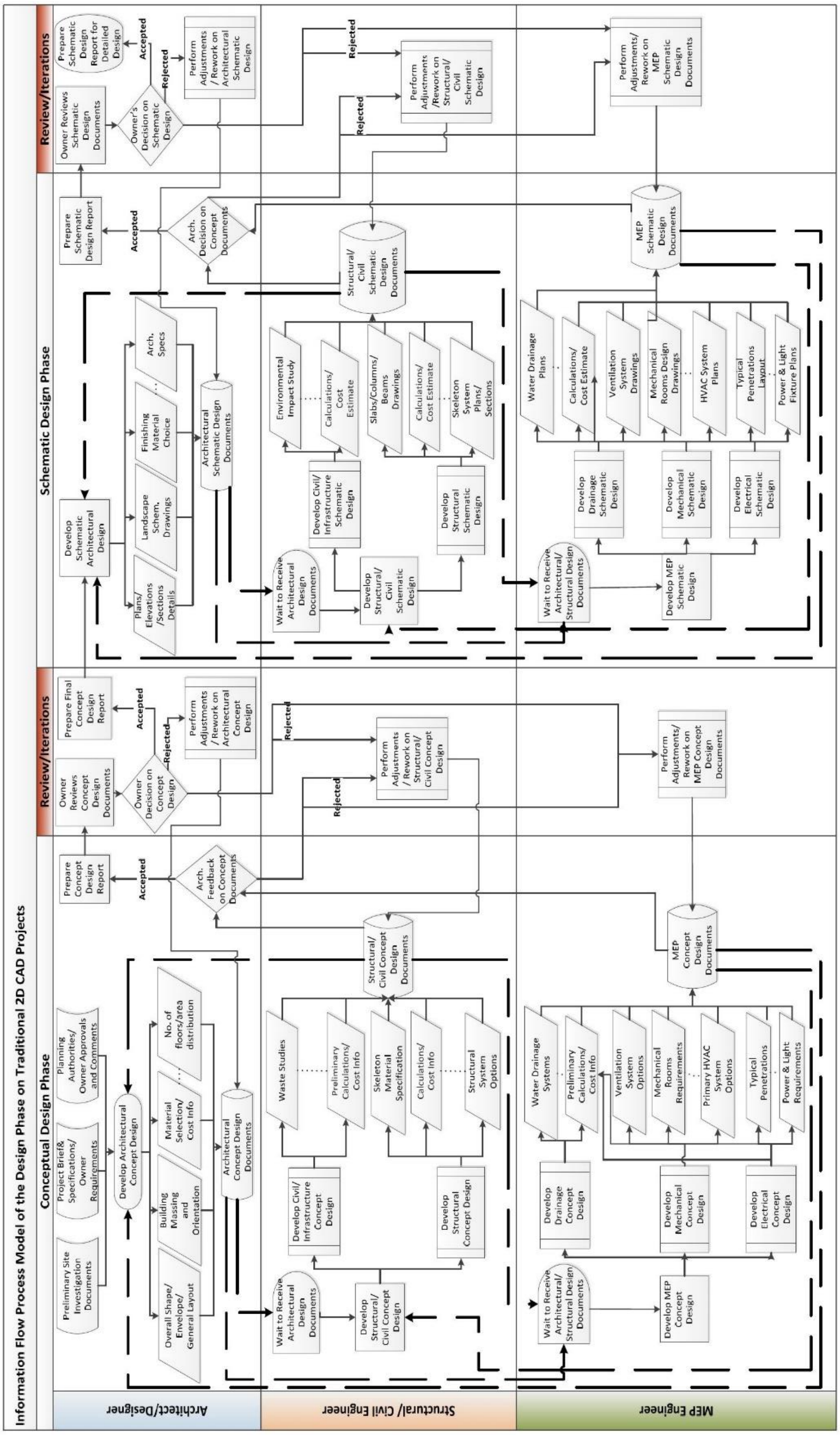

Figure 10: Information Flow Process Model of the Design Phase on Traditional 2D CAD Projects

concept documents. In the case of rejection, which normally comes late as it waits for the complete design input, the structural/ civil, MEP engineers, and architects have to perform adjustments and rework in the design process and go back again through several iterative loops before the design finally gets accepted. Upon the owner's approval, a final concept design report is generated to proceed with the schematic design phase. This phase proceeds in a similar manner as the concept design and includes several iterative and feedback loops, idle time and delays, rework and adjustments until the approvals of the architects and owners are received. This process will repeat for detailed design.

By reviewing the information flow of 2D CAD design phase, set of wastes can be identified:

- Transport: huge "paper exchange" of documents and information.
- Inventory: storing static "paper" documents which causes difficult access and finding of needed information in the right time.
- Motion: in traditional design approach just physical meetings for collaboration and exchanging the information is possible.
- Wait: slow manual "drafting" process wastes many times. Also waiting of different participant to receive the data to start their work is another component of the wait waste.
- Over-processing: processing paper-based documents.
- Over production: too much information too early, rework and late contractor involvement.
- Defects: many conflicts and errors will occur in the construction phase.

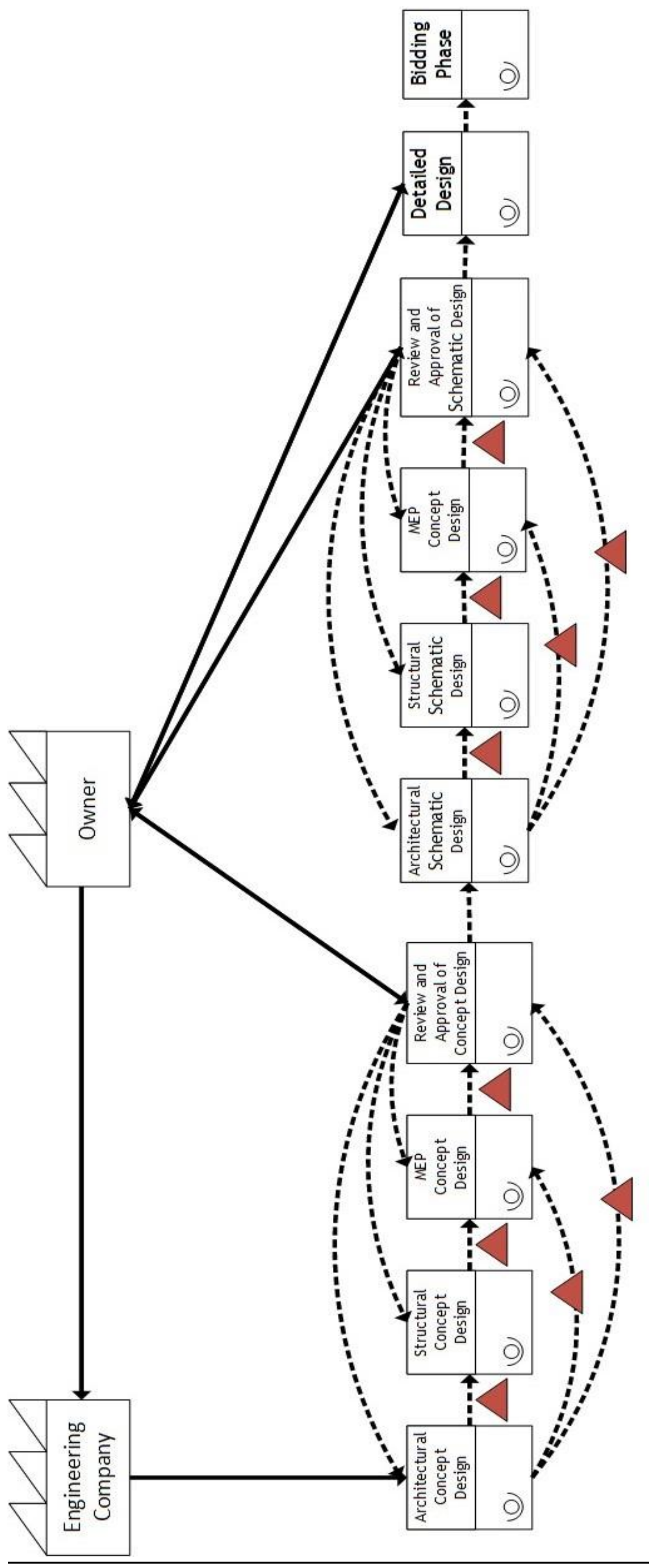

Figure 11: Current State Map

4.4 Future State (BIM-Based Design Phase)

The swim-lane diagram shown in figure 12 (Al Hattab & Hamzeh, 2013) is divided horizontally like the traditional 2D CAD design phase information flow swim-lane diagram. However, vertically, only the conceptual and schematic design phase are present as the information coordination, sharing, and owners' feedback happen during each of these phases and do not have to wait till the design is complete.

The concept design phase starts by developing the architectural concept in the BIM environment and generating deliverables that are incorporated into the building information model. Unlike the traditional 2D CAD design phase, the structural/civil and MEP engineers do not have to wait until the completion of the architectural design concept to proceed. Instead, early and easy data sharing is possible before data completion, thus the three cross-functional teams can develop their design concepts simultaneously. These concepts are modeled in the BIM environment, and result in individual comprehensive building information models that are integrated into one central model. This central model and individual models allow two-way information sharing between the different design participants in real-time as well as prompt adjustments of the model information after integrating and coordinating all the data.

In addition, the owner can get on board during the design concept development to provide his early feedback on the design criteria as the required deliverables can be extracted from the building information models at any time. This avoids the late "acceptance or rejection" decisions which result in massive time and cost consuming rework and countless design iterations as it happens on projects not using BIM.

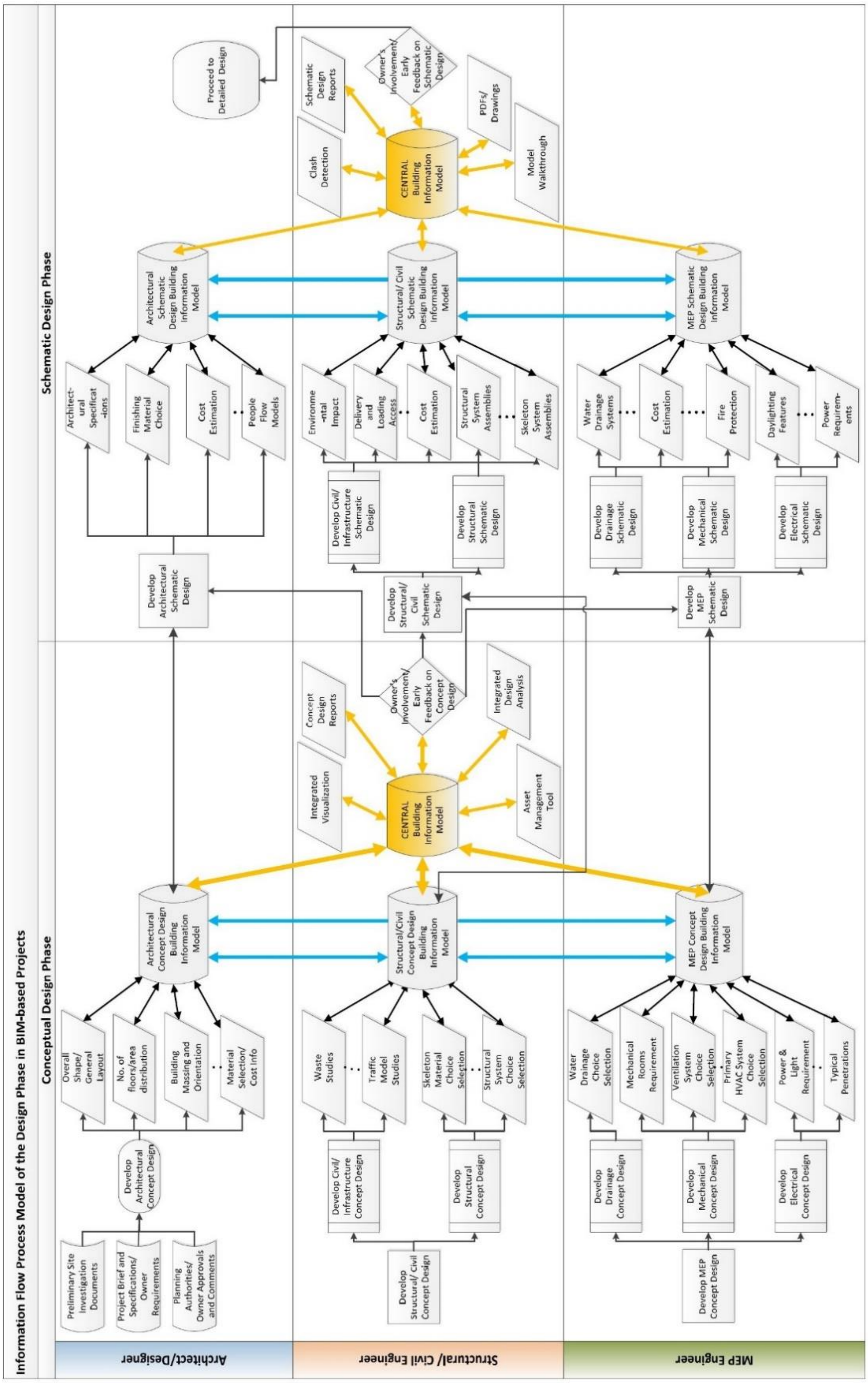

Figure 12: Information Flow Process Model of the Design Phase in BIM-based Projects

After the completion of the conceptual design phase, there is no need to start over and generate new models to develop the schematic design process. Instead, the previous individual building information models are further detailed in accordance to the required level of development (LOD) of the schematic design phase. This in turn saves time of starting over and wasting time. The schematic design process then proceeds in the same logic of the previous design phase.

In view of the current state conditions, a series of improvements by use of BIM in design phase can be proposed to eliminate the identified wastes, making the flow continuous, eliminating interruptions, reducing cycle times and the percentage of non-value adding activities and, ultimately increasing the quality of design.

- Transport: digital exchange vs "paper exchange" avoids duplication of effort.
- Inventory: BIM gives the opportunity of storage and reuse digital information vs storing static "paper" documents,
- Motion: the problems of physical meetings in traditional approach be solve by virtual design and construction, immersive web-meetings.
- Wait: quick digital changes/updates vs slow manual "drafting" process.
- Over-processing: digital consumption vs processing paper-based documents.
- Over production: BIM reduces the reworks and over production by providing enough and right information in needed time.
- Defects: digital 3D coordination helps to detect errors and any other clashes and mistakes before going to the site.
- Skills: by use of BIM, skills of the people can be better exploited instead of mundane manual paper-based tasks.

The future state map is presented in figure 13.

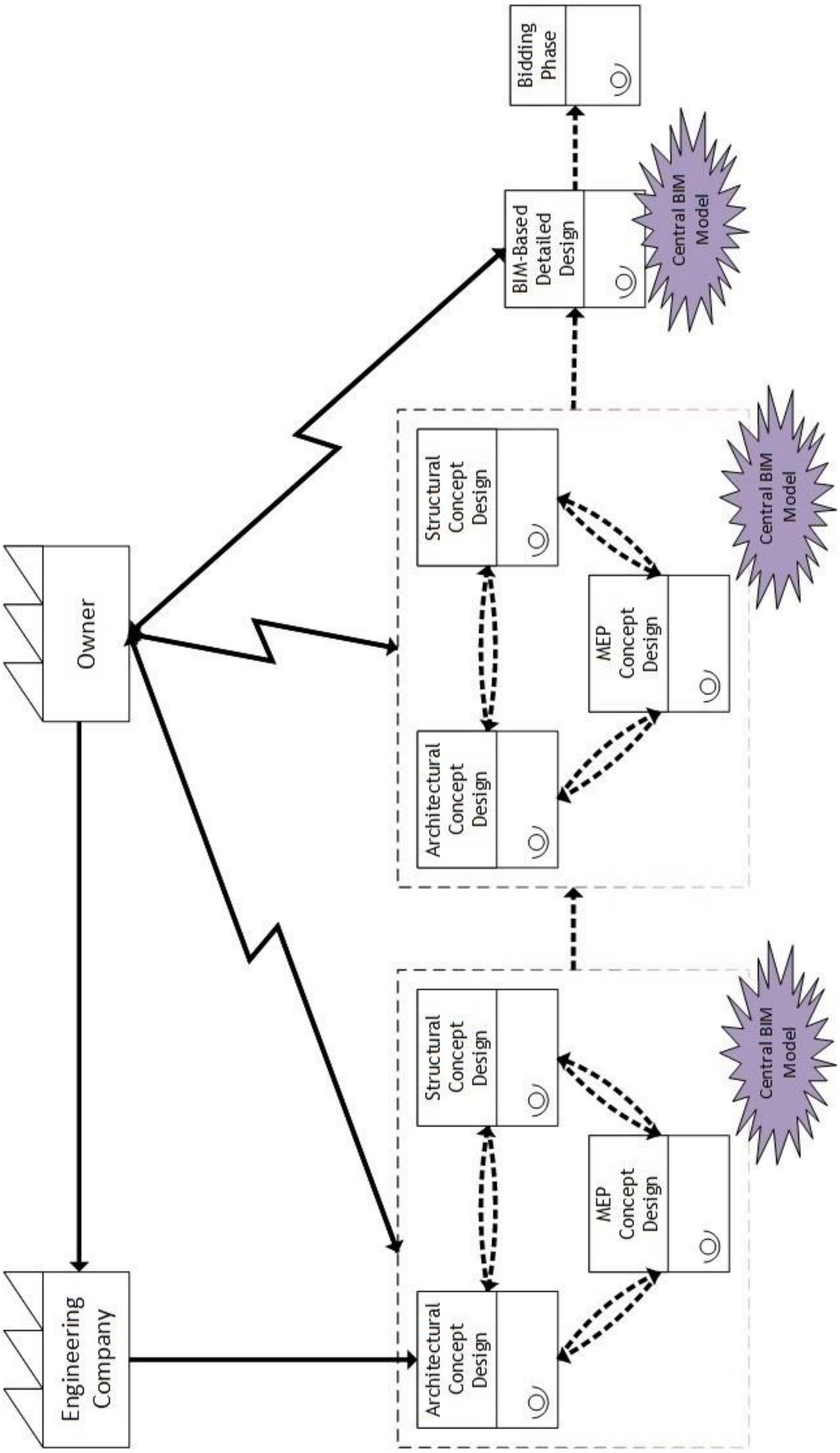

Figure 13:Future State Map

4.5 Discussion

There is a broad spectrum of possible BIM uses and benefits on construction projects. When BIM is realized as a process extending throughout the lifecycle of the project, instead of just a tool, the benefits can be realized. Along with its powerful ability to provide n-dimensional visualizations, scheduling and cost estimations, different building analysis (structural, civil, energy, safety…) and others, the power of BIM lies in its ability to make an integrated and collaborative approach to design and construction possible. In lean terms, effective communication, collaboration, and working towards a common goal are keen on generating value for the owner and reduce, if not eliminate, waste from the processes involved in delivering the project. To gain a better realization of these benefits and how BIM enables a lean design phase, a comparison between the two information flow process models is conducted and the results are discussed:

Timely Incomplete Design Information Sharing and Communication: In traditional 2D CAD design, the different participants must wait for each other's design completion; the data deliverables are piled in silos before they can be exchanged between the design teams. In such case, data can become obsolete, in other words, the data goes to waste. In contrast, in BIM-based design, early and timely exchange of incomplete information between participants is enabled by sharing and integrating the building information models of the teams at any point in time. This allows real-time design adjustments and development. The information is then always up-to-date, and the clear design intent visualization facilitates communication between players and allows for continuous information flow instead of interrupted batch flow.

Idle Time: The future state diagram of BIM-based design phases clearly shows the reduction in delays as opposed to the traditional design phases. As mentioned above, since data sharing can occur even before the design is complete, there is little or no idle time for the different teams when waiting to receive complete data information from each other. Idle time is a large source of waste in design and is a critical factor to be eliminated to prevent delaying the design generation phase requested by the owner. Through the use of BIM, such idle times and unnecessary delays of waiting are minimized or eliminated.

Owner Involvement and Value Generation: BIM enables the involvement of the owner/owner's representative and have him on board throughout the design progress by the ability to extract any design information when required from the integrated or individual models. In this respect, the owner's early feedback is of high value as it eliminates the late decision on the design data which, if rejected, results in rework, cost and time waste. Moreover, by involving the owner continuously as the design progresses, his value preposition will be properly translated throughout the project life cycle.

Iterative Loops and Rework: Iterative loops are a result of limited communication and information sharing. When data is shared in batches in an untimely fashion, it tends to go back and forth between the various design players in several loops before the design deliverables can exit the loop upon the acceptance of the architect and owner. When rejected, which is normal in design processes, the design deliverables have to be reworked. Since the deliverables are in 2D CAD, any adjustment of a certain concept or a drawing perspective, has to be reflected in all other trades/disciplines and views. However, by using BIM, this can be done automatically by modifying the model once in one view and all the other views are automatically modified, and the other involved players can be instantaneously notified of the required adjustments on their behalf (Hardin & McCool, 2015).This benefits the project reducing negative iterations and rework, thus saving time and preventing cost overruns.

Quality of Design: Designers can make use of BIM to explore alternative concepts, conduct value engineering and optimize their designs. BIM enables collaboration among the different participants and allows data input from everyone which generates a complete picture of the owner's design intent in everyone's mind. In this regard, the architects and engineers will work towards a common design of higher quality instead of having segregated ideas and lost quality achievement along the jumbled iterative traditional design phase.

The process models can be used as a source of data for other tools and applications to manage the design phase of construction projects in terms of cost, time, and resources.

Also use of BIM in the design phase, subsequently can impact on bidding phase. Compared with the traditional graphic design, BIM technology can better express the design intuitively, and can help each unit to correctly understand the construction drawings. Through the 3D model for architectural design function analysis, as a basis for comprehensive design optimization and design inspection.

Bill of quantities is the most important part in the bidding documents for major construction projects, there is some errors in calculation. But after BIM has been used, the calculation can automatically carry out by BOQ; there are many differences in this list with the traditional engineering quantity, which reduce the engineering quantity list compiled by the task. Through the application of BIM software, the profit of both sides has reached the most reasonable situation. By BIM technology, the bidding price can be optimized effectively. BIM can simulate the construction, which has very important significance for optimizing the funds. BIM can also be integrated into the capital management by associating the cost of the project with the schedule. The construction model can be combined with the plan in various stages, it can reasonably control the construction schedule, and it can calculate the expenditure of the costs. There are also helpful to make measures of all construction aspects in the bidding stage, BIM can show the information of funds in various stages of the bidding and can help to enhance the competitive advantage of the tender bidding company (Wei, 2017).

Chapter 5

Conclusion

Using Building Information Modeling (BIM) in design phase of Design-Bid-Build project delivery system propel it to Lean design. Even though DBB is the most common and popular project delivery system but still there are many inefficiencies due to the fragmentation and lack of information flows between design and construction phases.

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

In the conclusion answers to the three main questions of the research were provided:

- **How the information flows on traditional 2D CAD projects in the design phases of Design-Bid-Build delivery system is,**

For these reasons, Value Stream Mapping (VSM) as a powerful tool of Lean philosophy has used to model the information flow in traditional 2D CAD as the current state and later for BIM-based design management as the future state of design phase. By this, the relations and information flows between different participant and stages of conceptual, schematic and detailed design has revealed, the points where failure in communication occurs and the hurdles preventing stream-lined workflow highlighted.

- **Identifying the types of wastes and inefficiencies in traditional 2D CAD design projects,**

Before implementing lean principles and BIM to improve the design phase, it is necessary to realize that despite the iterative nature of the design phase in DBB projects, the major source of information waste are huge amount of paper-based exchange, processing and storage documents, physical meetings, slow and time consuming manual drafting process, unavailability of enough and accurate information in the right time, lack of standard for information sharing, need of too much time for decision making and inefficiency in exploiting all the skills of participants.

- **How BIM can impact on design phase information flow of DBB projects and propose the process improvements with respect to the 2D CAD approach.**

By comparing the captured information flow between two approaches of design management, the benefits of BIM use on design phase and how it can improve the process based on the types of wastes in traditional 2D CAD have proposed:

- Transport: digital exchange vs "paper exchange" avoids duplication of effort
- Inventory: storage and reuse digital information vs storing static "paper" documents
- Motion: virtual design and construction, immersive web-meetings vs physical meetings
- Wait: quick digital changes/updates vs slow manual "drafting" process
- Over-processing: digital consumption vs processing paper-based documents
- Over production: too much information too early. Rework. Late contractor involvement
- Defects: digital 3D coordination vs on-site coordination. Built it twice.

- Skills: better use of people skills and time resolving problems vs mundane manual paper-based tasks.

The results of the research show a high ability for transforming the traditional 2D CAD design phase into a lean design process using building information modeling in DBB projects.

Chapter 6 **References**

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