Lean Construction and Six Sigma Operations in Construction & Real Estate

Master Thesis

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

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Conceptual Formulation
Master Thesis for Mr. Sinan Bataineh.
Student number s0562755

Topic:
LEAN CONSTRUCTION & SIX SIGMA OPERATIONS IN CONSTRUCTION & REAL ESTATE

Nowadays, Construction & Real Estate Management field got more complex, complicated and has a lot of interfaces between management, design, execution and operation; that requires a high level of management, coordination and the use of new modern techniques tools; Six Sigma and Lean Construction Principles to overcome such challenges, as sustainability took part in every single field why we do not try to reach to the concept of sustainable management in construction & real estate.

The aim of carrying out this study is to reach a conclusion and clarify the doubts related to the below highlighted questions.

- How did the huge growth in construction & real estate sectors enhanced the classical management style?
- What are the management challenges that construction and real estate business are facing?
- Why do we need to analyse and overcome such challenges in construction & real estate sectors?
- What is the principle of lean construction and how it can be adapted to fit construction project's needs?
- What is the principle of Six Sigma and how it can be adapted to fit Real Estate needs?
- What is the link between such techniques and the principle of sustainable management?
- What are the conditions required to implement such techniques?
- How lean construction and Six Sigma approaches could help in securing projects funding and what is the effect on budget & cash flow? (Based on a real case study will be carried on)
- What are the lessons learned from carrying out this study and what could be possibly done to improve those techniques to meet expected future challenges?

Signature of the Supervisor

Abstract

Construction project's growing complexity has limited the efficiency of project management practices in achieving the major goals; quality, time and cost. Concerns arise about the necessity of adopting new techniques within project management as a solution. Lean principles achievements in the manufacturing industry management have paved the way for the opportunity of integrating these principles within construction project management to overcome project complexity challenges.

Studying the major challenges occur during project development and refer them to project management fields is the foundation of this study, referring different project challenges to major project management fields will make it possible to analyze the management processes, therefore, define areas of improvements. On the other hand, defining the major aspects of lean construction/Six Sigma along with supportive techniques.

This study aims to define and explain how Integrating lean/Six Sigma principles and techniques in project management processes can help in overcoming challenges.

This study will rely on researchers' findings related to project management challenges and the author's findings for challenges from two case studies. The findings will be analyzed and reflected to create the theoretical approach of integrating lean construction/Six Sigma within project management to overcome challenges.

Key words: Project Management, Project Management Challenges, Lean Construction, Six Sigma, Lean Project Management.

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List of Abbreviations

BIM	Building Information Modeling	**MARs**	Material Approval Requests
BOQ	Bill of Quantities		
CPA	Critical Path Analysis	**MDP4**	Msheireb Downtown Doha development project phase four
CPI	Cost Performance Indicator		
CPM	Critical Path Method	**MEP**	Mechanical Electrical Plumbing
DI	Ductile Iron		
DMAIC	Define, Measure, Analyze, Improve and Control		
EF	Early Finish	**MP**	Msheireb Properties
ES	Early Start		
F	Float		
HDPE	High-density Polyethylene	**NCRs**	Non-Conformance Reports
HSE	Health, Safety and Environment		
IFC	Issued for Construction	**OBS**	Organization Breakdown Structure
IGLC	International Group for Lean Construction	**PERT**	Program Evaluation and Review Technique
IRs	Inspection Requests	**PMBok**	Project Management Body of Knowledge
JIT	Just in Time	**QCS**	Qatar Construction Standards
KPI	Key Performance Indicators	**QMS**	Quality Management System
LBMS	Location -based Management System	**QP**	Qatar Petroleum
LBS	Location Breakdown Structure	**RAHP**	Rawdet Abel Heeran Project
LED	Light-emitting Diode	**RFIs**	Request for Information
		SPI	Schedule Performance Indicator
LEED	Leadership in Energy and Environmental Design	**TQ**	Time Qatar
LF	Late Finish		
LOB	Line of Balance	**UK**	United Kingdom
LPS	Last Planner System	**US**	United States
LS	Late Start		
LWS	Lean Work Structure	**WBS**	Work Breakdown Structure

Clarification

The main idea the author had as reflected in the approved conceptual formulation is to study the challenges related to project management in both construction and real estate sectors; in construction sector based on literature review and two case studies as part of his relevant experience; in real estate based on practical analysis within a real estate agency. Then, integrate the principles, techniques, and methodologies of lean construction within construction project management and Six Sigma concept within real estate management, the aim of that is to overcome management challenges in both fields.

Unfortunately, the author was unable to carry out the analysis and integration related to the real estate management due to the following;

- The author could not find a real estate agency that approves to carry on the practical analysis
- Information required for the study related to the real estate management is defined as confidential in most of the real estate agencies
- Six Sigma concept is a statistical approach; therefore, without any facts and data from real estate agencies, it is not possible to carry out the study.

Hence, the author in this study rectified the aim to cover the project management challenges in the construction sector and the integration of lean/Six Sigma in construction project management.

The new approach of this research under the title **Integration of Lean Construction/Six Sigma within Project Management to Overcome Challenges** covers the following questions;

- What are the project management challenges that project development is facing?
- What are the values that lean principle/Six Sigma can add to project development?
- How lean/Six Sigma techniques can be adapted to overcome construction project management's challenges?
- What are the barriers affecting the integration of lean principles within construction management

1. Introduction

This research aims to set up a theoretical basis for the integration of lean/Six Sigma principles within project management fields. This aim was based on the fact that most challenges faced during project development are related to poor and traditional project management practices. Project complexity has proved to be the trigger that led to reducing the efficiency of project management traditional practices; therefore, the adaption of new concepts within project management is required. Lean/Six Sigma principles achieved great results when applied in the manufacturing industry. From the fact that the construction industry has the potential to adapt the manufacturing industry theories; therefore, integrating these principles within construction project management might be the key solution for updating the traditional project management practices to overcome project complexity challenges.

1.1. Overview

The construction industry is one of the major fields that is affected by the advent of technology, the world is growing rapidly during the last decades due to the revolution in the field of technology which has affected project development (Jordan, 2017). Projects are a process of developing a unique product/service that serves the client's requirements, this process involves the use of techniques and tools defined under the concept of project management to organize the process of development (PMI, 2008). Henri Fayol and Henry Gantt are the godfathers of project management concept by the development of scientific management theory to serve the needs of project processes (Catalin Drob, 2009).

As projects complexity is increasing, concerns about the capability of project management theory to address new challenges arises, engineer Ohno has noticed these concerns in the field of production; therefore, he defined the principles and techniques of lean production to update the management process and eliminate the weaknesses of the traditional management style (Howell, 1999). Motorola's chairman, Bob Galvin noticed that the company's production has a high percentage of defective products; therefore, he emphasized on carrying out an analysis to define and rectify the root causes of these defects, Bill Smith a Motorola engineer, proposed to define a quality measurement system to control the production processes known as Six Sigma (McClusky, 2000). Since then, efforts were dedicated to adapting the same principles within the construction industry to overcome arise concerns.

1.2. Research questions

The following questions are the main concerns of this research and will be covered during the study;

- What are the project management challenges that project development is facing?
- What are the values that lean principle/Six Sigma can add to project development?
- How lean/Six Sigma techniques can be adapted to overcome construction project management's challenges?
- What are the barriers affecting the integration of lean principles within construction management?

1.3. Research Methodology

The research methodology will be carried by;

- Analyzing the outcomes from previous researches related to the topic
- Analyzing two case studies using the DMAIC model that the author participated in during his work experience
  - Case Study 1: Development of Local Roads in RAHP in Doha, Qatar (2014-2016)
  - Case Study 2: Development of Msheireb New Doha Downtown Project Phase 4, Doha, Qatar (2016-present)
- Defining theoretical approaches for the integration of lean/Six Sigma principles in defined project management fields.

2. Project Management

In this section, the author aims to define the concept of project management based on previous researches, highlight the phases of project management, explain the techniques/tools, and define the challenges faced; this will help in understanding the concept of project management, identifying the related challenges and clarifying why it has become the professionals' main concern lately.

2.1. Project Definition

As defined in the Project Management Cycle book “Project is like a "system" is a dynamic and complex whole, interacting as a structured unit with information flowing between the different elements that compose the system” (PM4DEV, 2015). So, a project is the interaction of different individuals in order to achieve a certain objective.

Projects are the reflection of a certain idea or thought into reality, according to the PMBOK (Project Management Body of Knowledge) 4th edition, a project is defined as a “temporary endeavor undertaken to create a unique product, service or result. The temporary nature of projects indicates a definite beginning and end” (PMI, 2008). In other words, a project is a set of activities which progresses continuously over time, it involves the allocation of certain resources, it has a determined budget, as well as a defined scope, timeline and set of operations to achieve a certain unique objective, service or a product. Although the project should be defined from the beginning, it gets clearer over time, also it is still possible that this definition can deviate as the project progresses, this can happen for many reasons such as; change in circumstances, financial issues, design challenges, managerial issues, and others.

As a summary, each project has three major pillars to fulfill in order to guarantee its success as illustrated in figure 1 (PMI, 2008);

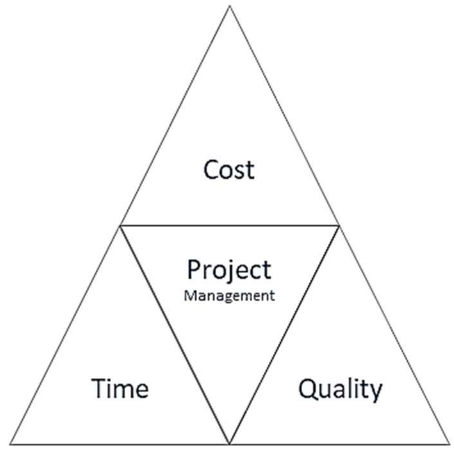

Figure 1 Project management pillars. Adapted from: (PMI, 2008).

- **Timeframe;** each project must be delivered within the time frame planned.
- **Budget;** a project must be delivered within the planned budget as money has always been the main concern for any project.
- **Quality;** projects are designed to fulfill some standards, aspects, and specifications which presents the project quality, any failure to deliver such will cause a project defect.

As mentioned above, these three pillars are the reason that the project management concept was established. The whole idea of the project management concept is to fulfill these pillars by establishing a certain balance while using specific techniques and tools.

2.2. Project Phases

Projects are complex dynamic structures, to simplify it, projects are broken down into phases. According to the Project Management Cycle book there are six major phases for each project (PM4DEV, 2015).

2.2.1. Project Initiation

The initiation phase is the phase where a project idea or concept is defined, funding is secured, and general planning is carried out; to determine the main goals and objectives of the project. Developing a new shopping mall in a certain location, upgrading an existing highway to increase its capacity, or even building a new bridge to connect between two major areas; all of them are examples for project ideas. During this phase the major concerns are;

- What is the project type?
- What are the main goals from developing this project?
- How much would be the approximate budget?
- How funding will be secured?

The outputs of this phase present a general view of the project concept, a project proposal, an approximate budget for project development and documents that clarifies the origin of funding. Once the project proposal is approved and funding is secured then, the project planning phase will take place (PM4DEV, 2015).

2.2.2. Project Planning

During this phase more details will be generated to support the proposal, the main task in this phase is to create detailed project plans, core planning; which are the plans that were briefly presented in the proposal and handle the issue of scope, budget, and schedule, and facilitating planning; which are the plans that clarifies all the factors and circumstances that interact with the project; the project team, stakeholders, information, risk, and contract management plans (PM4DEV, 2015).

Lawson defined the process of design in “How designers think—The design process demystified” as an endless process of findings and solutions, but because project development has a specific timeframe, design time is limited (Lawson, 1997). The design process is the combination of three main sub-processes; imaging, presenting and testing (Tilley, 2005);

- Imaging is the sub-process of creating images and models that reflects the design concept.
- Presenting is the sub-process of transferring the concept into drawings and specifications.
- Testing is the sub-process of assessing the presented design by ensuring the client’s requirements and needs are addressed.

While carrying out this phase, more details are revealed, the wrong assumptions in the proposal are rectified, the budget plan is modified, schedules and milestones are defined. The output of this phase is a full set of plans that allow the project to take place (PM4DEV, 2015).

2.2.3. Project Implementation

This phase is the reflection of all prepared plans on the ground. Basically; it is about carrying out the planned work and taking actions to ensure the project progresses as planned, in this phase teams are organized and assigned for different tasks and responsibilities, reports are generated, and deliverables are met (PM4DEV, 2015).

2.2.4. Project Monitoring and Controlling

This phase takes place in parallel with the implementation phase. The goal of this phase is to ensure that the project progresses as planned against its objectives, and corrective actions to be taken in case any deviation occurs or any change in the plans take place (PM4DEV, 2015).

2.2.5. Project Adapting

This phase handles all required actions to adapt the plans to fit in the project, based on the project monitoring and controlling phase, modified plans are generated and implemented. Change in circumstances and requirements needed to be considered to adjust the original plans and make sure the project is carried out smoothly. Besides, to that, the lessons learned throughout the project can be adapted as well to avoid any possible future conflicts during the implementation (PM4DEV, 2015).

2.2.6. Project Closing

This is the last phase of project development. Project closing is when all planned objectives have been met. All deliverables are ready to be transferred to the client (PM4DEV, 2015).

The aim of using management practices during project development is to organize the flow of information from phase to phase, coordinate between parties involved in each phase, and ensure project main three pillars are controlled.

2.3. Project Stakeholders

According to the PMBOK, the 4th edition project's stakeholders are all parties; persons or organizations who are involved in the development of a certain project and/or affected positively or negatively by the outputs of it.

In order to study the various effects of stakeholders on project development, and how can stakeholders affect the management style of the project, let us first shed light on the main project's stakeholders. those who actually have a key role in making management decisions and contribute directly to the project development.

Stakeholders are categorized into two major categories based on the effect they have on project development; Internal Stakeholders and External Stakeholders (Prabhu, 2016).

- Internal Stakeholders are those who have a direct influence on project development; client and client's representative, contractors, suppliers, and end-users (Prabhu, 2016).
- External Stakeholders are those who have an indirect influence on project development; local community, banks, and government (Prabhu, 2016).

Stakeholders always influence the development of any project and its deliverables. So, the project management team must ensure all stakeholders are identified and interactions are analyzed. As well as all possible interferences should be highlighted to avoid unexpected conflicts. From the PMBOK 4th edition the figure below presents the different parties influencing a project development (PMI, 2008).

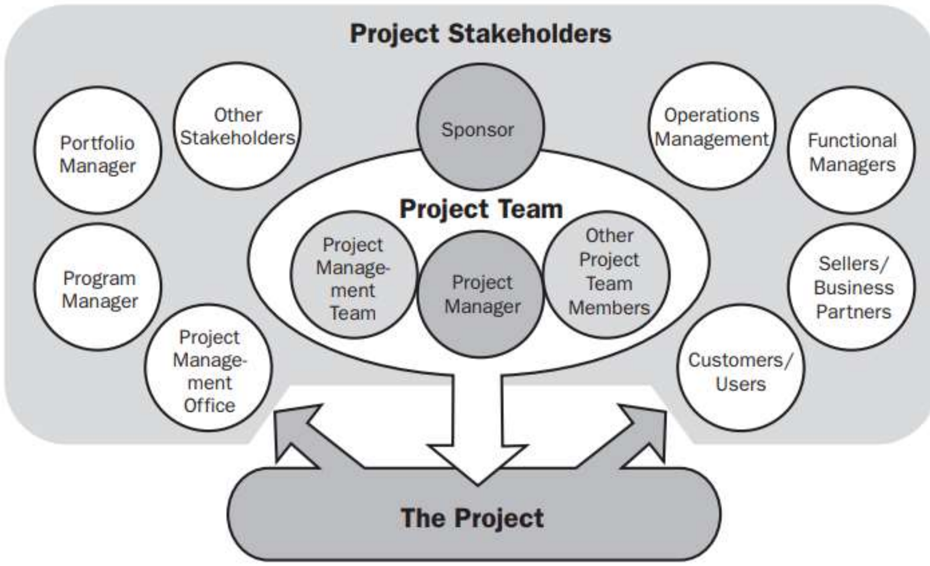

Figure 2 Project stakeholders. Source: (PMI, 2008).

- **Client**

  The Client is the owner of the project, it can be a person or an organization, public or private. it has certain goals and objectives to achieve out from a project. Usually the client hires a professional institute which is the project management consultant who is responsible to develop the project idea. Clients affect project development usually by requesting variations throughout the project lifecycle, or by causing some financial issues due to the lack of liquidity and delay in official payments (Smith & Love, 2004) and (PMI, 2008).

- **Project Management Consultant**

  This party is hired by the client to carry out all the planning work of a project; preparation of plans, coordination among project parties, and the preparation of the project proposal to obtain funding approval. It stays on board from the project initiation phase until the project closure (PMI, 2008).

- **Funding Institute**

  Known also as the sponsor, is the party who secures the funding of the project, it can be private or public. Most of the projects are funded by private banks. In order to obtain an approval for funding a project; the project management consultant must provide a project proposal that shows the project scope, budget required, payments schedule, project schedule, and other requested documents by the funder (PMI, 2008) and (Smith & Love, 2004).

- **Architect**

  The employer hires the architect to carry out all works related to the detailed planning; generating designs, estimating project costs, setting up standards and specifications (PMI, 2008).

- **Project Supervision/Consultant**

  The client/project management institue assign the project supervision consultant to follow up during the project execution, ensures all plans are followed, and specifications are met (PM4DEV, 2015).

- **General Contractor**

  Hired by the client to execute the actual physical work on site according to the detailed plans and drawings based on the contract agreed between both parties (PMI, 2008).

- **Sub Contractors**

  Hired either by the client or the contractor to execute certain services, special systems or deliver certain product/service (PM4DEV, 2015).

- **Suppliers**

  They provide certain services or supply required material for the execution of the project. A vendor list which contains approved suppliers are usually part of the contract documents (Prabhu, 2016).

2.4. Project Management Definition

As defined in the PMBOK, the 4th edition, project management is “the application of knowledge, skills, tools, and techniques on project activities to meet the project requirements.” (PMI, 2008).

In other words, project management is an art used to identify and analyze project needs, constraints and challenges in an early stage and through the project lifecycle as well as defining clear objectives to come with plans that meet the project’s final goals. This art carries out specific tasks involves the use of modern techniques and tools. Project Management tasks are carried out during the following project processes (PMI, 2008);

- **Project Initiating** is setting up the main goal or objective of the project
- **Project Planning** is defining and setting up project characteristics and requirement to meet the objective
- **Project Executing** is carrying out the actual physical work to reach the objective
- **Project Monitoring, controlling and adapting** is all tasks carried out during the execution to ensure the project is on track as planned
- **Project Closing** is handing over the completed project to the Client/end user.

Nowadays, manpower has become a certain concern, with the increasing rate for labor force especially after the 2nd world war due to the shortage of available labors, the idea of developing management concepts and techniques to overcome this challenge took place. CPM and PERT are the most common management techniques established in order to organize the project works, resources and cost. Afterward, the involvement of specific software that supports these techniques helped in taking the project management concept to another level that would help to cut down both manpower requirements and costs (Matheu, 2005).

As discussed earlier that project management interferes in all project phases from the project kick-off to the project closure, project management addresses major aspects to ensure a secured process for project success, project management performs in the following knowledge areas;

- **Project Integration:** the integration of the three main project management processes together, where all planning, execution, and control inputs are merged to ensure successful project implementation (PMI, 2008) and (Burke, 2003).
- **Project Scope Management:** ensure all requirements by client, sponsors, and stakeholders are addressed, defined within the scope of work and reflected into activities to carry out the project. It includes work authorization, scope planning, scope definition, scope change management, and scope verification (PMI, 2008) and (Burke, 2003).
- **Project Time Management:** all processes and practices to ensure that the project's tasks and activities are fitting in the project planned timeframe, this will

help in avoiding unnecessary interruptions or delays. These are ensured by establishing a proper activity definition, a sequence of work, estimation of individual activities duration, assigning the correct work calendars and proper control is carried out during the execution of project activities to avoid slippage in progress (PMI, 2008) and (Burke, 2003).

- **Project Cost Management:** all processes and practices that ensure the project budget is met; proper estimation, monitoring the project cash flow, monitoring the resources and cost controlling (PMI, 2008) and (Burke, 2003).
- **Project Quality Management:** by ensuring that all aspects, specifications, and standards which serve the main project objectives are defined, as well as proper implementation is carried out; where these aspects, standards, and specifications are met. These can be guaranteed by preparing a quality management plan, quality assurance plan, and quality control plan during implementation (PMI, 2008) and (Burke, 2003).
- **Project Human Resource Management:** this is one of the most important aspects to consider during project management, the aim here is to involve the right professions and skills in project development (PMI, 2008) and (Burke, 2003).
- **Project Communications Management:** all the processes required to ensure a proper means of communication is established to share project information, issues and to coordinate among project participants. These are achieved by implementing communication planning, information distribution, project meetings, progress reporting, and administrative closure (PMI, 2008) and (Burke, 2003).
- **Project Risk Management:** risks are uncertain events that might occur during project execution, it has a very critical influence on the project's budget if it is not analyzed and considered properly during earlier stages, effective risk management is achieved by implementing risk identification techniques, risk analyzing techniques, establishing a proper risk management plan and ensuring a risk control is being carried out during the project lifecycle (PMI, 2008) and (Burke, 2003).
- **Project Procurement Management:** is managing the processes of purchasing the required materials and services for the project development. This can be

handled by generating a consistent procurement plan, a proper source selection, and contract administration (PMI, 2008) and (Burke, 2003).

- **Project Stakeholder Management** basically manages the relationship of stakeholders to the developed project by defining involved stakeholders, analyzing their interests, power of decision, anticipating the potential decisions and acting to avoid project disruptions (Prabhu, 2016).

In order to ensure proper project management is carried out in the previously highlighted knowledge areas, a set of techniques and tools are required. Projects are getting more complex by time so, the use of combined multiple techniques to follow up and the ensure project's success became necessary.

2.5. Project Management Techniques

The whole idea of project management is to achieve better understanding, communication, and coordination among all parties on board to ensure the project is delivered on time, within defined budget and according to the agreed quality. In order to organize all inputs to support achieving the three main pillars of any projects, therefore techniques and tools have been invented over time; Gantt Chart, CPM, PERT, Network Diagram, WBS, OBS, LOB and Linear Planning (Burke, 2003).

2.5.1. Gantt Chart

Gantt Chart or known as bar chart is a concept developed by an American called Henry Gantt (1861 - 1919), his idea was designing a visual aid for simplifying project tasks over time (Burke, 2003), Gantt Chart is a graphically presentation to reflect and analyze project progress over time by comparing the planned tasks against the actual progress carried out, the idea of this chart is representing the flow of tasks graphically which makes it easier to follow and monitor, although most of the project's tasks are complex and have complicated sequence among each other (LOUARNE, 2003). The Gantt Chart shows different project tasks on the y-axis while it has a time scale presented on the x-axis as illustrated in figure 3 (Burke, 2003).

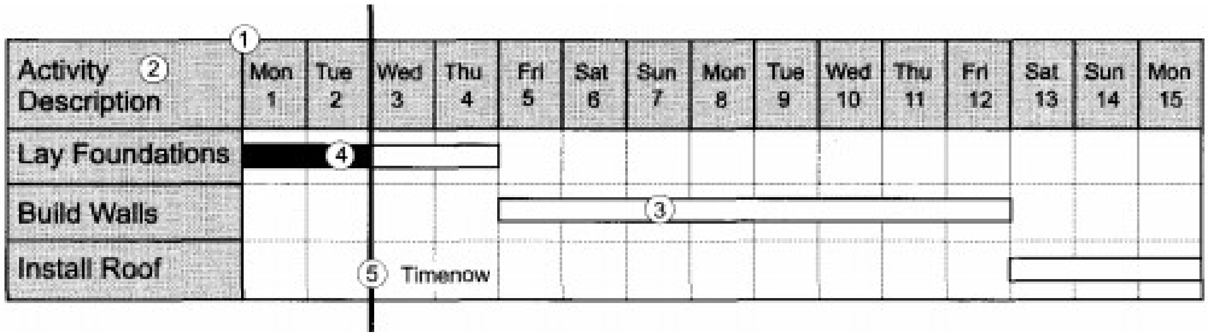

Figure 3 Representation of Gantt Chart. Source: (Burke, 2003).

- Number 1 represents the x-axis where the timescale is reflected
- Number 2 represents the y-axis where the tasks are defined
- Number 3 represents the taskbar
- Number 4 is the actual progress highlighted on a certain activity
- Number 5 is called the data date which presents the cut-off date of the Gantt Chart update.

Pros of using the Gantt Chart as a planning tool for Project Management can be summarized under the following (CLARK, 1923);

- Easley generated and understood by project managers
- It shows the start and finishes dates for each individual task
- It reflects the duration of each individual task
- It allows the presentation of major events as milestones
- Most importantly it provides a visualization of project tasks over time.

Cons of using Gantt Chart as a planning tool for Project Management can be summarized under the following (CLARK, 1923);

- It does not present the actual dependencies among tasks
- It does not show the resources assigned to each task
- It does not show the location of planned tasks
- It does not show the driving path of the project or what is known as the critical path.

The Gantt Chart was a great additive to the project management concept, although due to its cons a development of other techniques was necessary.

2.5.2. Network Diagram

As discussed earlier that the Gantt Chart concept lacked the presentation of any logical sequence among project tasks, therefor the concept of Network Diagram was invented by Flagle, the US Navy and Remington Rand Univac in 1956, although it was not published in the Journal of Industrial Engineers until April 1961, the Network Diagram is a presentation of project tasks in the form of a network, the concept is presenting all logical relationships among the planned tasks, activities either as boxes or arrows as presented in figure 4 (Burke, 2003).

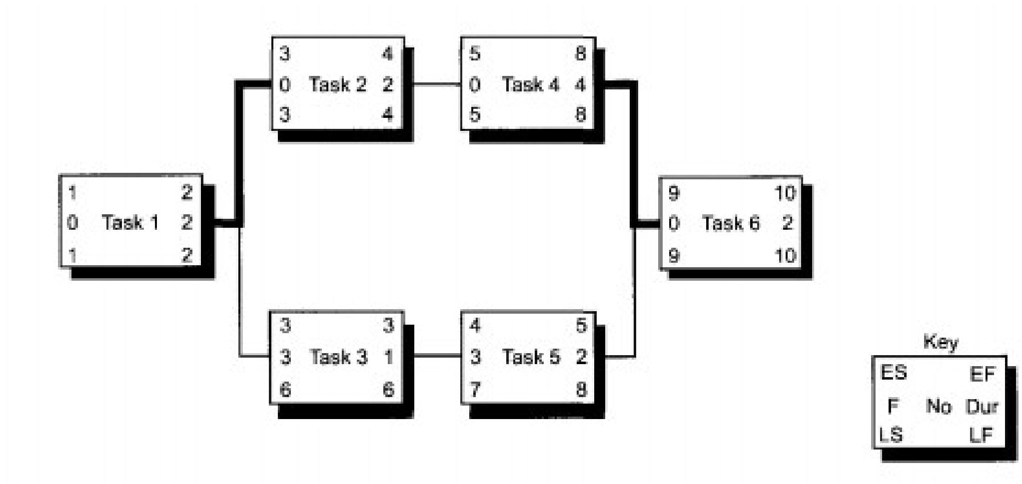

Figure 4 Network Diagram. Source: (Burke, 2003).

The invention of Network Diagram concept was the kick-off to bring management techniques to another level, in France, professor Roy developed networks and schedules, while in Russia, the development of 'Lattice Planning' took place, but most important in the UK the development of CPM technique took place for the purpose of maintenance overhaul at Keadby Power Station (Burke, 2003).

2.5.3. CPM and PERT

CPM and PERT are the most common two network-based project management techniques, both reflect the structure of project activities and the flow of execution.

CPM which stands for critical path method also known as CPA which is critical path analysis is a project management technique derived from the network diagram concept, it was developed around 1957 by Remington Rand Univac in order to dedicate a tool that helps in improving the planning and control of their turnaround time. Although CPM had a great result in the project management field, the growth of usage was so slow due to a lack of management knowledge and foundation for this technique (Burke, 2003).

CPM is a managerial approach used to set up plans for project developments by breaking down the project into operations with defined durations and sequence, the result is a set of activities connected in a logical flow from start to end, after that analysis are carried out to determine the project longest path; which is the set of activities that are driving the project completion knows as critical path, and it has a float of zero, this means any delay in the execution of such activities will lead to the delay of the entire project. CPM is a technique used when project activities are certain and well defined, in other words, it is possible to assign accurate durations to each individual task (Surbhi, 2019).

PERT stands for Program Management and Review Technique, it is a managerial technique used to plan uncertain projects where activities are uncertain and is hard to accurately estimate durations, this technique relies on assigning three durations; optimistic, most likely and pessimistic for each individual task based on statistical and probability approaches (Surbhi, 2019).

2.5.4. WBS and OBS

WBS stands for work breakdown structure while OBS stands for organization breakdown structure, both are network-based techniques used to analyze and simplify the workflow during the development of a project. WBS reflects the breakdown of the project's works into smaller packages which are easier to handle and plan. On the other hand, OBS is a breakdown for the parties involved in certain project development, it also includes the responsibility assigned to everyone in the organization (Burke, 2003).

Integrating both networks results in assigning different packages to responsible parties to follow up during the execution of a project, which helps to identify who is responsible? And what are the works related? (Jebrin, 2018)

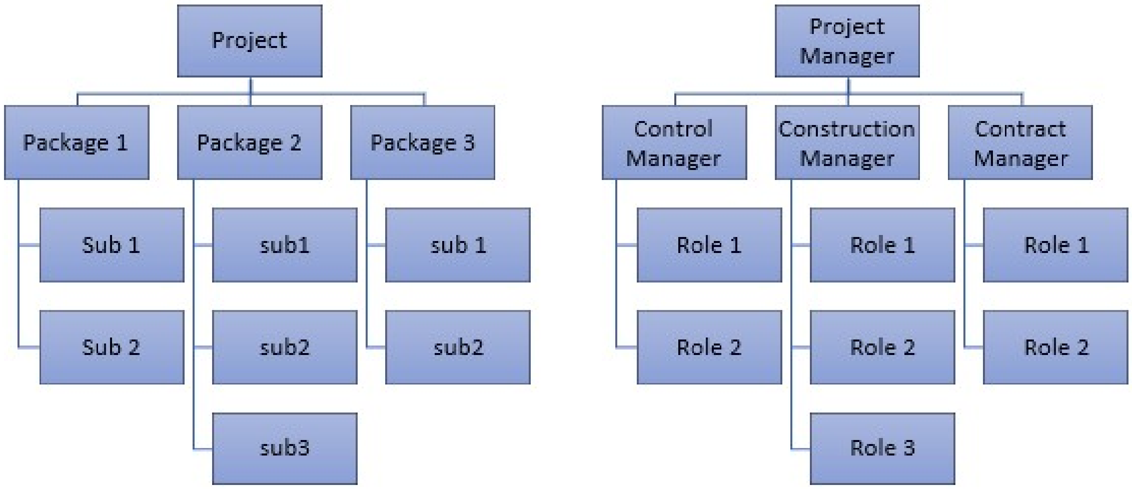

Figure 5 Project WBS and OBS.

2.5.5. LOB and Linear Planning

LOB which stands for line of a balance is a technique that was first originated to serve industrial manufacturing and production control, the main objective was to ensure a continuous flow of activities on a production line will be maintained in order to avoid disruptions, therefore unnecessary waste time. The LOB Scheduling Technique basis was found by the Goodyear Company in 1940, later it was developed by the US Navy in 1950 for the programming and control projects. Due to the popularity of the CPM approach, it had an impact on the use of LOB techniques. Linear planning which is one of the LOB technique forms was developed and used for the planning of highway construction projects, and pipeline projects; it supports the idea that work will flow continuously during the execution of the project (Pai, Verguese, & Rai, 2013).

What makes LOB different than other techniques is the fact that in this technique; location plays the major role, by using this technique a proper presentation of tasks versus both time and location is clear, therefore all possible interactions and conflicts during project development can be identified and sorted out during the planning stage (Soini, Leskela, & Seppanen, 2004).

Illustrated in figure 6 is a chart represents the idea of using LOB for project planning;

- The x-axis represents the time scale

- The y-axis represents the location or section
- The inclined lines represent different project tasks.

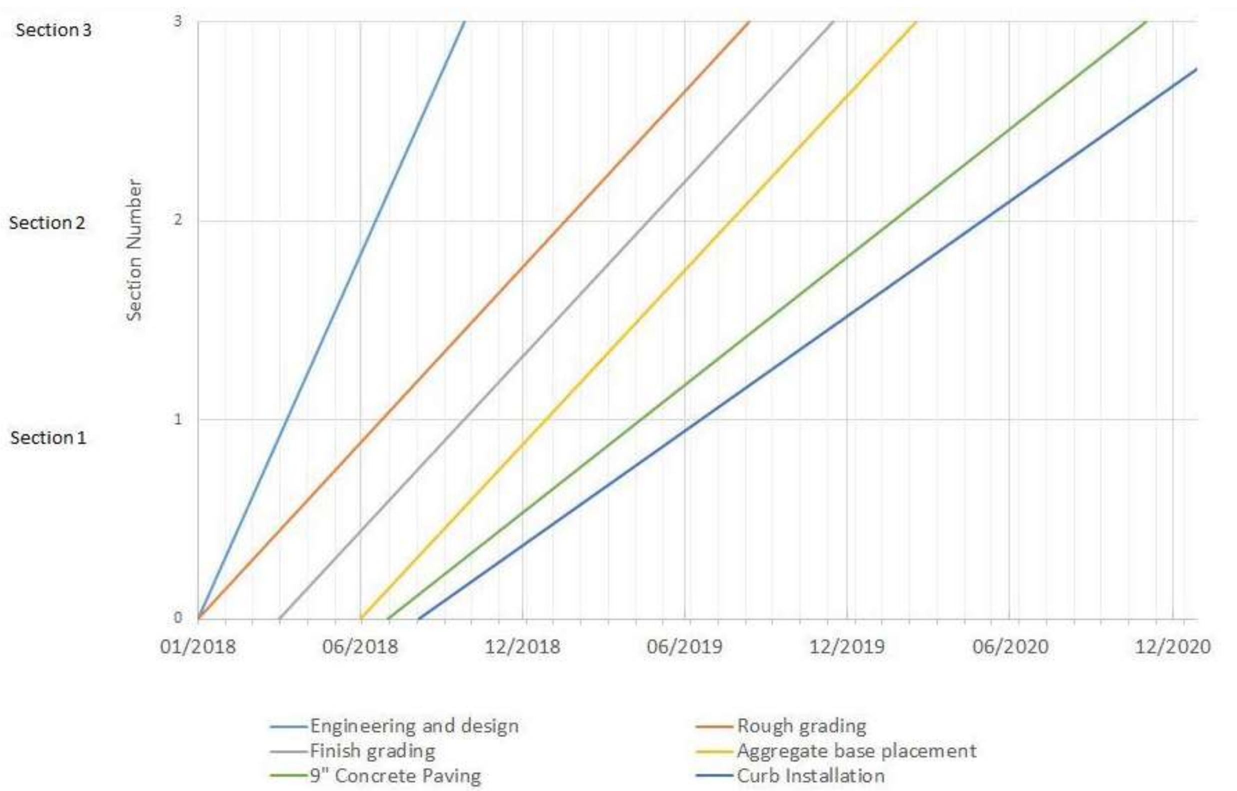

Figure 6 Line of Balance. Source: (ADROIT, 2018).

Pros of using LOB as a planning tool for project management can be summarized under the following (Soini, Leskela, & Seppanen, 2004);

- It shows the location of each activity
- It presents the flow of activities
- Presents possible interactions and clashes between tasks
- It shows the starting and finishing dates for each individual task
- It shows the duration of each individual task
- Most importantly it provides a visualization of project tasks over time.

Cons of using LOB as a planning tool for project management can be summarized under the following (Soini, Leskela, & Seppanen, 2004);

- It does not present the actual dependencies among tasks
- Useful in projects where activities are repetitive; buildings and highways
- Limited use when the project has unrepetitive activities.

There are other techniques as well used from project management, most of the techniques share the same basis but have different approaches or tools, the selection of proper management techniques depends on the type of project developed. Each technique can be adapted to serve the management decision decided throughout the project lifecycle, but most important is that all management challenges must be identified, analyzed and sorted out.

2.6. Project Management Challenges and Issues

A project is successful when the main three pillars of project management are met; project delivered on time, within budget and according to the agreed quality. Project management aim is to balance and fulfill these major aspects through the project lifecycle, but challenges may cause failure to fulfill these aspects.

Projects face different challenges during their lifecycle, challenges which lead to disruptions, additional costs, delays and faulty execution of works.

According to the study carried out by Hewitt in 1991 where he analyzed possible challenges that affect project development from scope management and its effect on schedule, he found out that change of project scope, change in circumstances and/or conditions leads into unexpected disruptions and delays which has to be dealt with by either accelerating or terminating parts of the scope which will eventually cause extra cost or lower the project quality (Hewitt, 1991).

While the study which was carried out by Vicky and Scrivener in 1993, where they shed the light on possible conflicts that might occur related to financial problems they found that conflicts occur due to determination of the agreement, payment related issues, the site, and execution of work, time related, final certificate and final payment (VICKY & Scrivener, 1993).

Kumaraswamy in 1997 studied the effect of variation on the project execution and came up with the conclusion that variations occur due to many reasons, he highlighted that the most common reasons are variation due to site conditions, variations due to client changes, variations due to design errors, unforeseen ground conditions, ambiguities in contract documents, variations due to external events and interferences (Kumaraswamy, 1997).

According to Yates study in 1998 where he discussed the major concerns disrupting construction works, the conclusion was showing that variations, ambiguities in contract documents, inclement weather, delay in issuance of design information and drawings, delay in possession of site by contractor, delay by other contractors employed by the client due to miscoordination, and postponement of part of the project are the main challenges to project execution (Yates, 1998).

Sometimes improper early planning can cause certain disruptions in project execution, as explained in the study carried out by Mitropoulos and Howell in 2001 that project uncertainty, contractual problems, financial position, and cultural issues which all must be considered in the early planning stage can cause a huge disruption and add additional cost to the project (Mitropoulos & Howell, 2001).

According to the research carried by Patil in 2016, he identified four major challenges that affect project management; undefined goals, change in scope, improper risk management, and impossible deadline (Patil, 2016).

- Undefined goals either when goals are too many, too big, not specific or not written

Figure 7 Mistakes in setting project goals. Source: (Patil, 2016).

- Change in scope; many changes in scope affect the time and cost of the project which eventually will lead to losing control of the management task if not handled properly

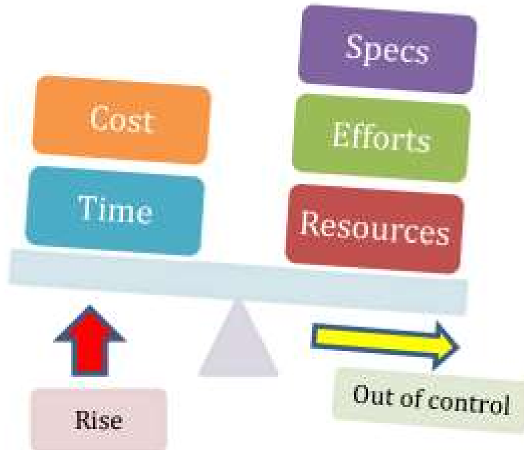

Figure 8 Scope changes effect on projects. Source: (Patil, 2016).

- Improper risk management; faulty process in identifying, analyzing, controlling and reducing risks
- Impossible deadline; faulty estimation for project duration and budget.

According to a study carried out by Nina Ryd in 2014, where the study analyzed the management challenges that concern different clients in Denmark, Norway, Finland, England and Australia, he reached the conclusion that the main challenges clients face are Information and data complexity, communication needs, models development, safety concerns, sustainability aspects, value management, the value added from implementation of BIM (Ryd, 2014).

During the author's experience, it was noticed that project management faces severe problems in communication among project participants, which usually leads to unnecessary delays, reworks and extra costs. Also, one more challenge would be the conflict of interests among project participants.

Based on all the studies mentioned above most of the project challenges occur due to poor or improper planning in the early stage which affects the execution in the implementation phase leading to disruptions, delays, and additional unnecessary costs. That's why professionals in the construction field have been more concentrated lately to develop and implement new techniques that support the concept of project management during project lifecycle. Table 1 presents the challenges faced during the project development related to project management according to different researches.

Table 1 Project Management Challenges.

Research Study	Main Challenges Defined
Winning Contract Disputes: Strategic Planning for Major Litigation, Hewitt 1991.	• Change in Scope of Work • Change in Project Circumstances
Review of Australian building disputes settled by litigation, Vicky and Scrivener 1993.	• Contract Agreement • Payments • Time Delays • Handing-over Procedure
Conflicts, claims and disputes in construction. Engineering, Construction and Architectural Management, Kumaraswamy 1997.	Variation orders due to; • Site Conditions • Client Changes • Design Errors • Unforeseen Ground Conditions • Ambiguities in Contract Documents • External Events
Conflict and Disputes in The Development Process: A Transaction Cost Economics Perspective, Yates 1998.	• Variations • Ambiguities in Contract Documents • Weather Conditions • Design Issues • Contractor Mobilization • Coordination between Participants • Interruption of Works
Model for understanding, preventing and resolving project disputes, Mitropoulos and Howell 2001.	• Project Uncertainty • Contractual Problems • Financial Position • Cultural Issues

Project Management Challenges, Patil 2016.	• Undefined Goals • Change in Scope • Risk Management • Phases and Milestones
Construction Clients Challenges - Emphasizing Early Stages, Nina Ryd. 2014.	• Information and Data Complexity • Communication Management • Safety • Sustainability • Value Management • Implementation of BIM
Based on Project Management literature review in this study.	• Communication Management • Limitations in planning tools • Stakeholder Management

As a conclusion the challenges that face project management can be summarized under the following categories;

Challenges related to the scope of work; change in scope, additional scope, design issues and change in specifications.

Challenges related to timeframe; phases, milestones, and delays.

Challenges related to cost; cash flow, financial issues, wrong estimation, payments, liquidity damages, fluctuations, and inflation.

Challenges related to management processes; communication, risk management, responsibilities, and interests.

Challenges related to external factors; weather conditions, politics, cultural conflicts and governmental regulations.

3. Lean Construction and Six Sigma

In this section, the concept of lean construction and Six Sigma will be defined according to related studies, techniques/methodologies, and characteristics that will be clarified to set up the basis of integrating these techniques/methodologies within project management.

The construction projects have become more complex, many challenges are affecting the development of these projects, starting from the planning stage till the closure stage, therefore adapting new techniques must take place to influence the management style.

Construction industry has been facing frequent delays in project delivery, budget overruns and failures in achieving the desired quality. On the other hand, manufacturing industry managed to sort out these issues by developing different techniques, lean production and Six Sigma are two of the major concepts that specifically targeted these issues, form this point researchers in construction field dedicated efforts to adopt lean production and Six Sigma principles into construction field to overcome time, cost and quality challenges.

Lean construction and Six Sigma are the most common approaches lately in the construction field, in this chapter, the author will shed the light on;

- The history of lean principles and Six Sigma concept
- What is lean construction?
- What is Six Sigma?
- What are the characteristics of Lean Construction and Six Sigma?
- What are the techniques of Lean Construction?
- What are the methodologies of Six Sigma?

3.1. History

The concept of lean started from the idea of eliminating waste in the production industry, to be more specific Engineer Ohno who was working for Toyota had a vision that waste can be minimized in the Toyota car production company, by focusing on the concept of flow based production system, he reached the idea that by ensuring a continuous flow of production waste is minimized, production rates are increased. One of the major concepts he based his theory on was the production is running based on demand, therefore, he ensured that no extra costs exist from secondary services; no inventories or intermediate stores (Howell, 1999).

Waste has always been a huge concern in the production industry, therefore there are many conflicts in the definition of waste, most people consider physical waste is the only type of waste, but actually when talking about waste there are many types, for instance, failing to meet the customers' requirements is considered to be waste, waiting time is waste, rework is waste, and the list goes on (Howell, 1999).

The idea of Engineer Ohno was stopping the line of production to minimize waste when there is no demand, at the beginning it was weird for the workers to shut down the whole production line, the employees believed in more production, but on the other hand Engineer Ohno proved that production based on demand achieved better results and minimizes waste (Howell, 1999).

The concept of Six Sigma was developed in the 1980s in Motorola, Motorola's chairman, Bob Galvin noticed that the company's production has a high percentage of defective products; therefore, he emphasized on carrying out an analysis to define and rectify the root causes of these defects (McClusky, 2000).

Each production system has a certain quality level, a quality level represents the percentage of defective parts generated through a process, for instance, 99% quality level means that the output would have 1% defects, (McClusky, 2000) highlighted the following examples for a 99% quality level systems;

- 99 % quality level in airport management means that two planes per day might have an accident
- 99 % quality level in power generation means that each month 7 hours of no electricity is acceptable.

A Motorola engineer, Bill Smith, proposed to define a quality measurement system to control the production processes known as Six Sigma. The aim of this system was to achieve a quality level where a margin of two defective parts per billion is allowed in the production line. The concept of this system relies on defining the valuable aspects related to costumer's requirements, setting up an effective production system to produce products according to the requirements, and controlling the production to reduce the defects to two parts per billion (KRISHNAN & PRASATH, 2013) and (Raisinghani, Ette, Pierce, Cannon, & Daripaly, 2006).

3.2. Definition

Production and construction industries have been in conflict for ages. Although the construction industry has been rejecting many theories from the production industry, no one can deny that there are many similarities both industries share. The concept of lean production and Six Sigma was adapted to fit and serve construction needs, main aspects may benefit and serve construction project development by (Howell, 1999);

- Defining a clear set of objectives to achieve defined targets
- Optimizing project activities and increase productivity
- Optimize project processes in order to enhance the management style
- Implement control aspects in the production industry to fulfill construction control needs
- The application of just in time concept (JIT) to eliminate the waste of invaluable works.

3.2.1. Lean Construction

Lean construction was derived from the concept of Lean production system, which supports the idea of maximizing value and minimizing waste, using specific principles, techniques and processes, in order to apply them in a new project delivery process. So lean construction is the principle of raising the value of construction works mainly by reducing waste generation, optimizing construction processes, focus on valuable works, and achieve better communication and coordination throughout the project life cycle (Ansah, 2016).

Lean construction is the combination of principles, techniques and tools adapted from the production industry to fulfil construction project needs during planning and execution, as stated earlier the three major concerns in project management are time, cost and quality, lean principle goals are increasing the product value, increasing costumer's satisfaction, and reducing waste generated, all of these goals help in supporting the idea of better project management while handling time, cost and quality.

Lean construction supports two major practices in construction (Howell, 1999);

Planning: by defining clear strategies to achieve project objectives, these strategies will be supported by different processes during the project life cycle.

Control: by defining specific processes to ensure that the works are carried on as planned and eliminate the possibility of errors during execution.

3.2.2. Six Sigma

There are many perspectives to define the concept of Six Sigma based on the implementation field;

Harry and Schroeder in 2000, defined Six Sigma as “A disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them” (Harry & Schroeder, 2000).

From a strategic point of view, Six Sigma is defined as a strategy to define goals, establish processes and produce products in an efficient way (Snee, 2000).

From a business point of view, Six Sigma is defined as a systematic methodology to achieve high product/service value through the costumer’s satisfaction (Antony & Banuelas, 2002).

As stated by Pheng and Hui, Six Sigma is “a ‘‘cultural and belief’’ system and a ‘‘management philosophy’’ that guide the organization in repositioning itself towards world-class business performance by increasing customer satisfaction considerably and enhancing bottom lines based on factual decision making” (Pheng & Hui, 2004).

3.3. Principle and Basis

Lean and Six Sigma are both adapted from the manufacturing industry. These concepts serve the goal of enhancing the production processes considering main principles and basis.

3.3.1. Lean Concept

Koskela in The Foundation of Lean Construction, 2002 defined Lean 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” (Koskela, Howell, & Ballard, 2002).

Koskela managed to introduce the idea that construction can be treated as a production process, with the efforts of The International Group of Lean Construction (IGLC), the basis of the lean construction principle was established around minimizing waste, optimizing operations and reach Client satisfaction (Salem, Solomon, Genaidy, & Luegring, 2005).

The concept of lean evolved overtime but all were based on the main concept to produce a system that delivers a costume product when ordered considering the following (Howell, 1999);

- Identify valuable aspects and eliminate the invaluable tasks
- Maintain a continuous production flow based on demand
- Create reliable flow and ensuring no rework is carried on by delivering the perfect product
- Ensuring customers’ satisfaction is a valuable factor.

The main idea of Lean is to shed the light on more important aspects instead of the traditional known ones, demand instead of supply, optimizing flow instead of maximizing flow, value generation and minimizing waste.

Lean is a principle and a way of thinking, from this point it can be adapted to fit the needs of any industry as well as the construction industry (Ansah, 2016).

Glenn Ballard and Gregory A. Howell in Competing Construction Management Paradigms published in 2004, shed the light on the reasons that they believe will support the adaption and evolution of lean production into the construction field, they relied on (Ballard & Howell, 2004);

- The great results achieved by the Toyota Production System
- Weak and unsatisfactory performance of construction projects which needs to be improved

- Lack of an efficient project management theoretical proposal in construction.

3.3.2. Six Sigma Concept

Six Sigma is a statistical term that represents a high level of quality in an organization, the term quality is reflected by three factors; inputs, processes and outputs, each factor of them influences on the organization's overall quality level. Six Sigma concept targets the organization's quality level by implying the methodologies of the DMAIC model to reach major principles (The Council for Six Sigma Certification, 2018);

- Customer-focused improvements
- Continuous process improvements
- Variation
- Removing waste
- Equipping people
- Controlling the process.

The DMAIC model stands for define, measure, analyze, improve and control (Tehrani, 2010);

- **Define:** this is driven by determining the costumer's requirements, specifying key processes, developing an organizational structure, identifying project objectives, and anticipating possible risks.
- **Measure:** this is driven by collecting related data to processes and defects, measuring the performance of processes, and establishing measurement systems.
- **Analyze:** determining the defect's root cause through extensive analysis.
- **Improve:** this is driven by setting up alternatives to rectify findings from the analyze step and assessing the efficiency of these alternatives.
- **Control:** this is driven by creating a control plan to ensure proper implementation of the alternatives.

The basis of Six Sigma is to integrate the DMAIC model within the organizational practices to achieve the main principles, this will enhance the quality level of the organization.

3.3.3. Similarities

Construction projects are considered as a long combination of processes to develop a certain unique product or service, this concept somehow matches the idea in the production industry, therefore breaking down the construction project into subprojects which also develop a unique product will help in applying the lean production and Six Sigma theory. Based on the principles defined for each concept, lean construction and Six Sigma share the same focuses as presented in figure 9; increase value, stabilize workflow, reduce waste, achieve perfection, and reach costumer's satisfaction.

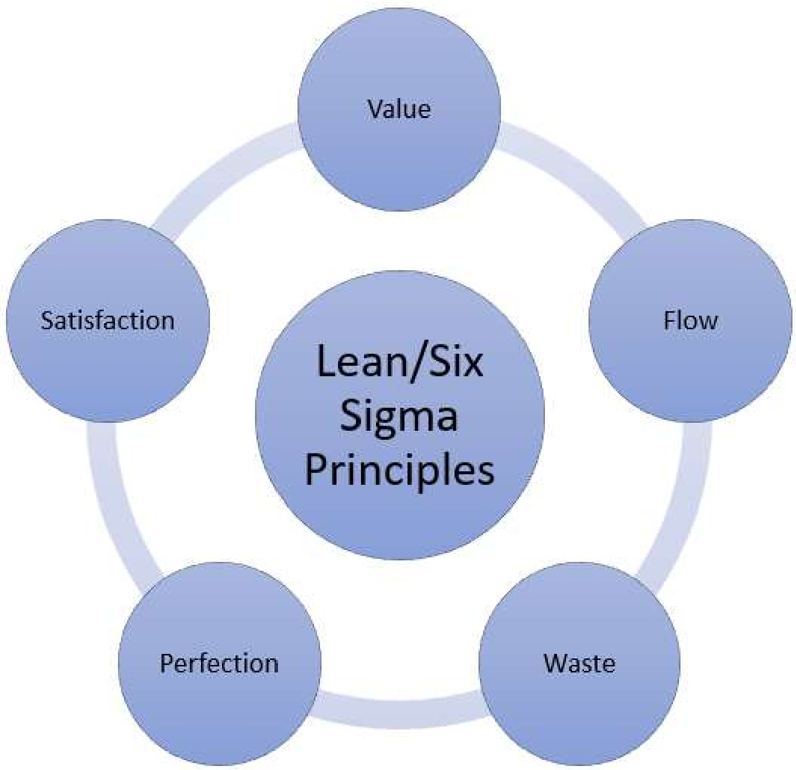

Figure 9 Lean/Six Sigma principles.

The main principles for both concepts can be achieved by considering the followings;

- Defining strategies to support key processes
- Eliminating defects by solving root cause problems

- Focusing on the valuable attributes of a project while eliminating the non-valuable attributes which leads to minimizing waste
- Monitoring site actions and ensuring faulty practices are rectified
- Executing works when required instead of creating chaos
- Enhancing flexibility through different processes will lead to overcoming sudden challenges during execution
- Reducing the process cycle time
- Maintaining a good relationship with project participants which creates a healthy environment during project execution.

3.4. Characteristics

The use of Lean construction and Six Sigma through project lifecycle have a positive impact on management style and project performance, both techniques have characteristics to add for project management, these characteristics reflect the benefits of applying lean construction and Six Sigma concepts in project management.

3.4.1. Value of Work

In construction, each project represents a unique product that is designed and constructed according to the client's needs, therefore, the client must always be involved during the project development and delivery process. The maximum possible value is achieved through meeting the client expectations, ensuring their satisfaction and needs while taking into consideration offering the best price and quality (Garrido, Pasquire, & Thorpe, 2009).

Kano model is a presentation of the relationship between valuable attributes vs. client satisfaction; as illustrated in figure 10. Where the must-be attribute represents the aspects that must be performed to ensure client's satisfaction, while the one-dimensional attribute is these were the client specified certain requirements which must be fulfilled, finally the attractive attributes are additional aspects optionally provided which has a great influence on client's satisfaction (Huang, 2017).

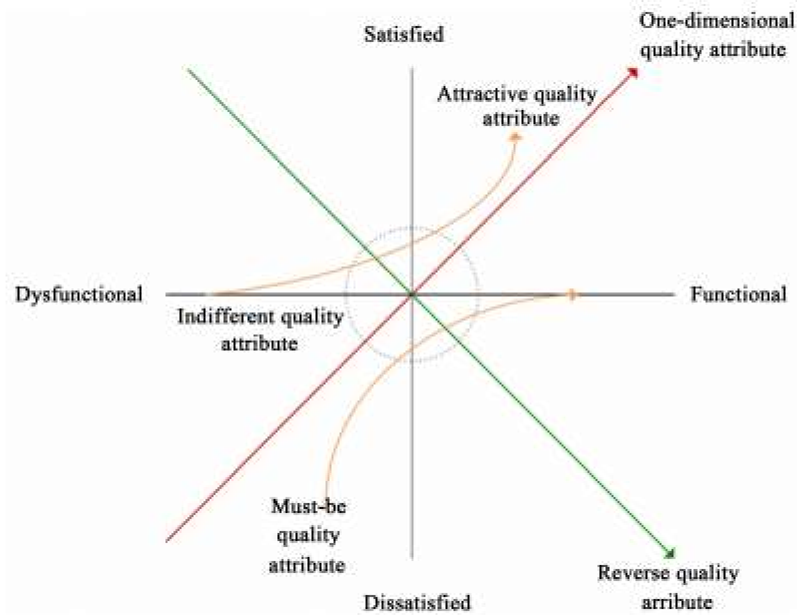

Figure 10 Kano model. Source: (Huang, 2017).

Lean construction theory focuses on the aspects that add value to the client while on the other hand eliminate the aspects which have no additional value. “Engineers and economists alike see value in terms of the features that product or services has” (Shillito & De Marle, 1992).

Lean construction aims first to understand the true value of the project, then establish the processes that ensure the required value is met and eliminates the effect of invaluable attributes (Garrido, Pasquire, & Thorpe, 2009). The processes defined to achieve the project objective is controlled using Six Sigma techniques to eliminate the possibility of any defects during the processes.

3.4.2. Minimizing Waste

In order to shed the light on the advantages that lean construction and Six Sigma can bring to the field of construction waste management, we must define construction waste and its categories.

Waste in general is defined as invaluable products, services or practices that occur while carrying on a certain activity within a time period. In construction waste can be defined as all activities and processes that consumes resources without adding any value to the project development (Ansah, 2016).

According to the study presented in figure 11, waste in construction is around 53% which is extremely high compared to waste in manufacturing which is only 12%.

Figure 11 Construction vs. manufacturing waste percentage. Source: (Aziz & Hafez, 2013).

Researches have analyzed many categories of waste in construction, Shingo in 1984 categorized the construction waste into seven different categories based on the waste cause; construction system, material stocks, construction operations, transportation waiting time, oversupply, and defects. Koskela in 1992, identified waste in construction as execution defects, construction rework, design mistakes, scope changes, and oversupply of material. In the research carried out by Nikakhtar, Hosseini, Wong, & Zavichi in 2015 about application of lean construction principles to reduce construction process waste they categorized construction waste under three main categories; waste on construction site, waste due to external factors and waste in construction processes. Figure 12 presents the waste categories in construction accordingly.

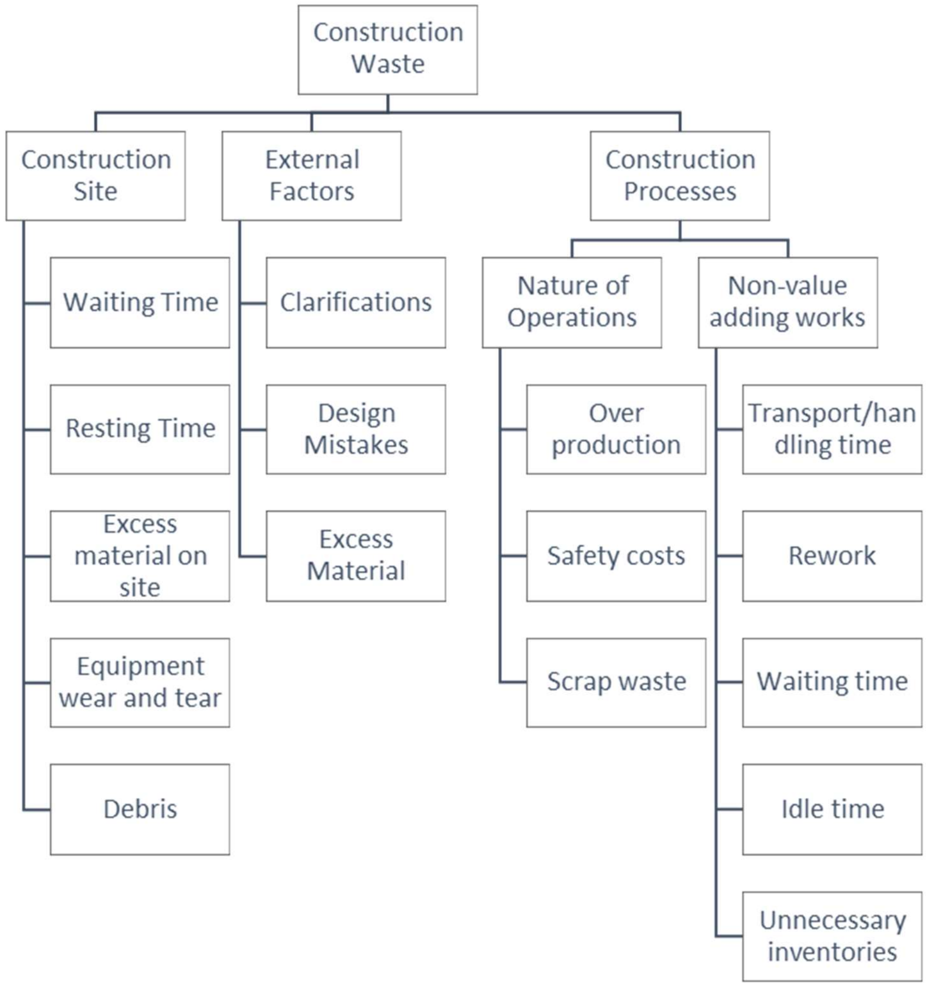

Figure 12 Waste Categories in Construction. Adapted from: (Nikakhtar, Hosseini, Wong, & Zavichi, 2015).

It can be noticed from the figure above that majority construction waste are under two main categories; physical waste and waste generated through processes. Debris is all type of waste generated through construction, renovation and demolition processes. Researchers idea of waste is all non-value attributes activities that adversely affect project performance as well as the negative impact on cost overruns and delays. Also, most generated waste is related to the construction processes, the aims of implementing the lean construction and Six Sigma is to determine the waste generated through construction processes and eliminate it (Subramani, Khan, Raj, Najeeb, & Rajan, 2018).

This can be achieved using the lean construction and Six Sigma techniques which will be defined, explained and integrated into the following sections.

3.4.3. Optimizing Workflow

A construction project is a set of activities that run from project start till project end, and no construction project does not face interruptions that lead to suspension of works, delays and even extra costs. Many factors are affecting this workflow and causing interruptions such as design factors, permits, resources, operations, material supply, management decisions, communication issues, and other external factors. Project management aims to minimize these interruptions as possible and ensure a smooth workflow through the project lifecycle. Project management practices have been struggling about analyzing the workflow and interruption causes due to lack of theoretical analysis approach, while, in the production industry workflow is the basic concern in any production line, as known production lines maintain a continuous workflow during their production and with the assets of lean principles this flow has been optimized in a way to ensure maximum production possible with less waste generated. After the adaption of lean principles into construction, the questions arise about the solution that lean principles can bring into construction workflow. In construction, the workflow is defined as the implementation of information, processes, and resources together in the form of activities during the project lifecycle to achieve project main goals (Garcia & Fischer, 2016).

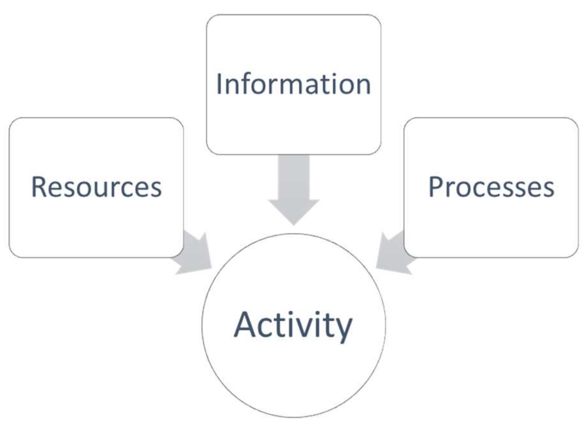

Figure 13 Factors affecting construction Activities.

So by carrying out analysis on each individual activity within a construction project, this analysis includes defining all required resources, information and processes needed to execute the activity, the interaction of each activity with other activities and the sequence of activities carried on to avoid any conflicts during execution, the result is achieving an optimized construction workflow as presented in the figure 14.

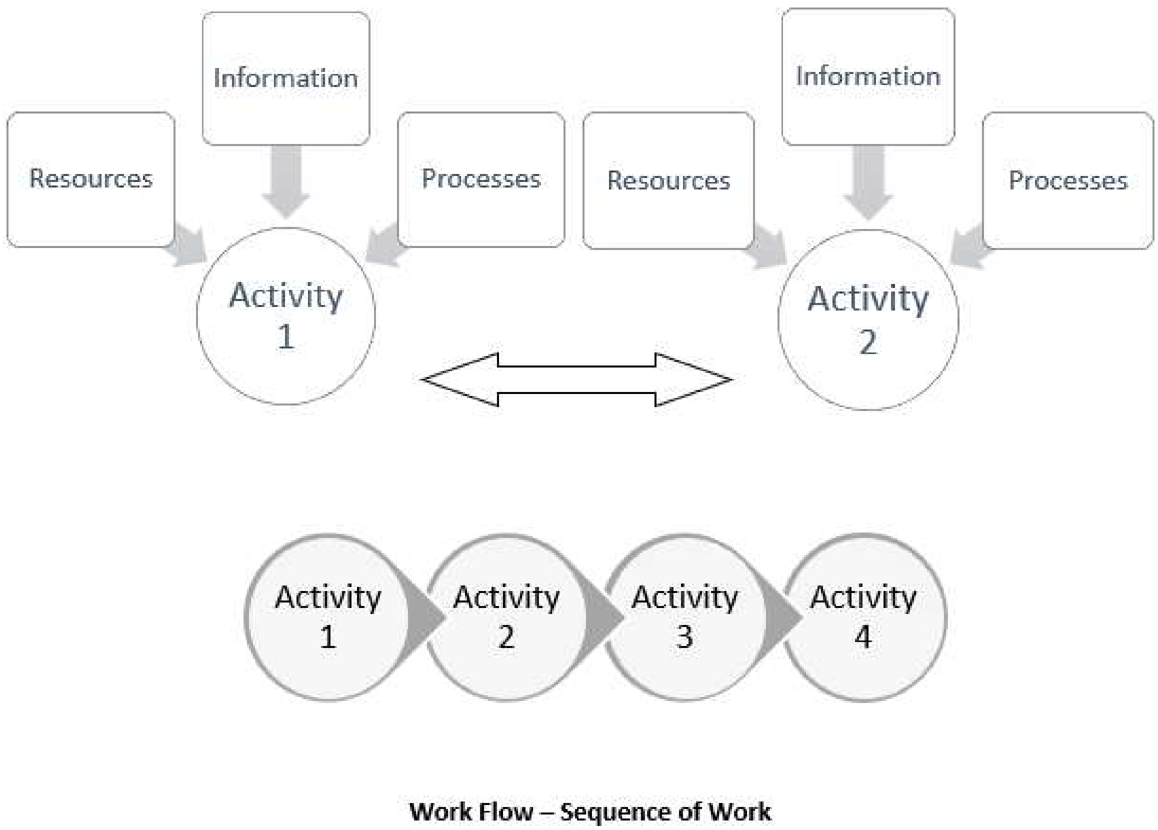

Figure 14 Optimized construction work flow.

3.4.4. Just in Time

The concept of just in time was established in the production industry by Engineer Taichi Ohno and his fellows working at Toyota, their beliefs were to change the production system from estimated demand to actual demand in order to reduce work in process inventory, working capital, and production cycle time. Reduction in flow variations will be achieved by implementing this approach, resources were encountered only when required which led to the elimination of extra handling costs of resources. While construction is a different type of production, it was challenging to adapt to the same concept, as construction has more uncertainty and flow variations. Therefore, construction is a schedule-driven process, this means if the execution goes perfectly then no problems will occur in execution, but unfortunately, that is far from reality as construction execution is affected by many factors which interrupt the work and cause certain delays.

The use of buffers in construction is one approach to overcome delay in execution, two types of buffers are indicated in construction schedule; schedule buffer and plan buffer. Schedule Buffers is the buffer considered for the resources required to carry out a certain activity. Plan Buffers is the buffer considered for the availability of the work front, due to the construction work sequence (Ballard & Howell, TOWARD CONSTRUCTION JIT, 1995).

JIT approach suggests the replacement of schedule buffers with plan buffers in the schedule by ensuring all causes of interruptions are handled, therefore, no delays will occur in the schedule, this can be achieved by studying and handling all causes of delay before occurrence. Once certainty is guaranteed, the resources can be provided only when required. Figure 15 illustrated the required analysis to ensure the implementation of JIT strategy (Ballard & Howell, TOWARD CONSTRUCTION JIT, 1995).

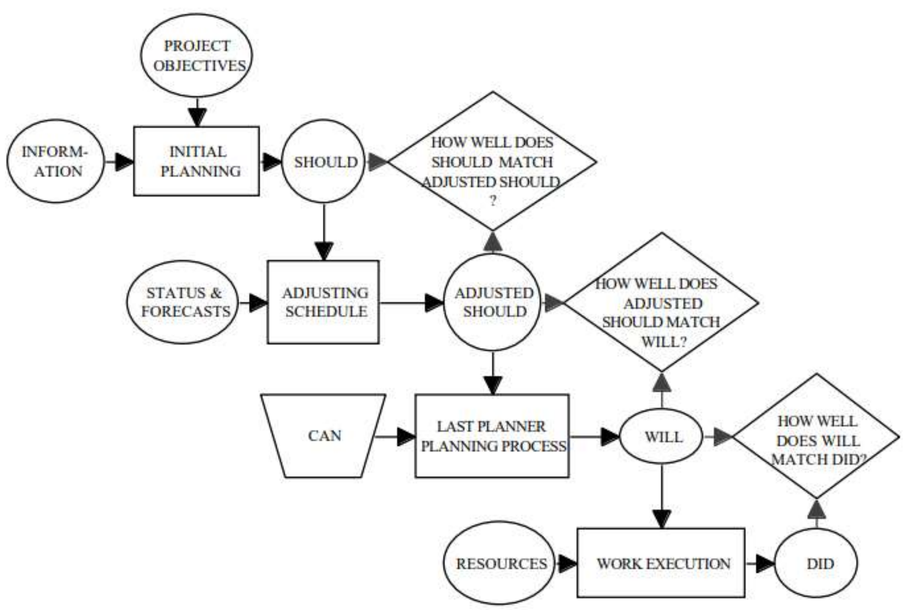

Figure 15 Analysis for JIT strategy implementation. Source: (Ballard & Howell, TOWARD CONSTRUCTION JIT, 1995).

Carrying out such analysis prior and during the project execution will reduce the factor of surprise, buffers will be considered between processes only which means resources will be mobilized once Workfront is available, overhead costs related to resources handling will be minimized accordingly.

3.4.5. Reduce Cycle Time

Cycle time is the duration required to produce a certain product in the production line. In construction, it is defined as the required duration to achieve a set of tasks that are repetitive during project development; construction of structural floor, finishing works on a certain floor, road works for a defined chainage, etc. Cycle time is determined by estimating the duration required to carry out each individual task within the set of activities, each task depends on a group of resources with certain productivity to execute it, therefore, the productivity of each task is the main key to reduce cycle time. Also, the sequence of work and construction methodology may extremely influence the cycle time. Based on the above mentioned the main three factors affecting activity cycle time are (Ridwan, 2016);

- Productivity; measurement of resource’s performance on a certain task at a specific time.
- Construction Sequence; the logic and relations between executed tasks
- Construction Methodology; the techniques and tools used for task execution.

Lean Six Sigma concept focuses on improving productivity which will positively impact the cycle time, the productivity is improved by carrying out the required analysis using the integration of three techniques; DMAIC, Kaizen and 5S.

The process of improving productivity can be summarized as; define the task’s components, measure the component’s productivity, analyze room of improvements, define corrective actions, control the implementation of these actions and measure results.

Lean Six Sigma as well organize the flow of tasks and the methodologies used to execute an activity, organizing the flow of tasks will lead to better sequencing of work and elimination of clashes/interruptions, therefore, reduce the cycle time. Also, improving construction methodology by defining more efficient techniques and tools will reduce cycle time as well.

3.4.6. Making Improvements

Lean and Six Sigma concepts are not only handling the relations between processes, the concepts also handle analyzing each process itself, looking into all the inputs and factors affecting a single process, let us take construction activities for instance, as stated before each activity is affected by three major factors; resources, information and the processes required to execute the activity. Also, each factor of these is affected by subfactors as well, figure 16 represents the factors and subfactors affecting the execution of a certain activity.

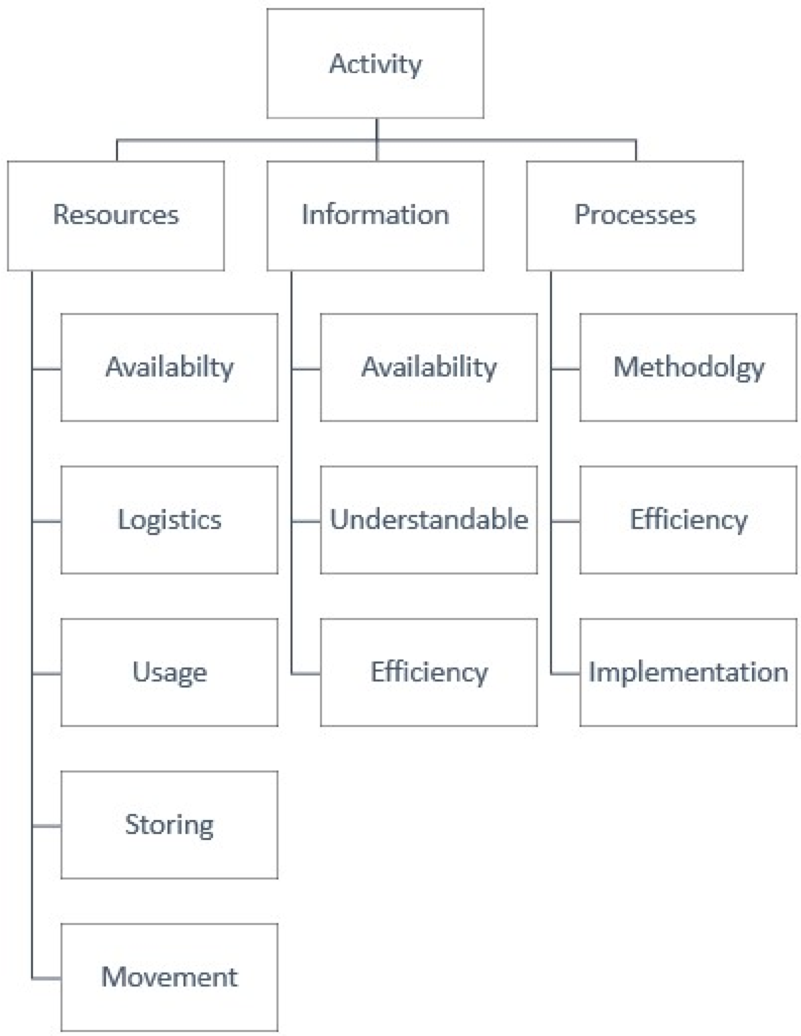

Figure 16 Factors and sub factors affecting a construction activity.

Improvements can be considered in every single subfactor; for example, with the implementation of JIT; resources availability can be controlled and organized, improving logistics on site and in stores will minimize the waste of time by organizing the site access and the material allocation. Also, will improve the use of space in stores and on-site, this will help in eliminating waste due to storage and movement of resources. The same applies to the information, making sure the information is delivered on time, in the right form, and within the required efficiency will eliminate reasons for misunderstanding and wrong implementation. Managing the processes by defining methodologies and ensuring the correct implementation will eliminate the faulty execution of work, therefore, no rework will be required.

According to a case study carried by (Nowotarski, Paslawski, & Matyja, 2016), where they analyzed the realization of the construction of an office building "Baltic" in Poznan (Poland).

- Duration from November 2014 to February 2017
- No of Floors: 19 Floor
- Built-up Area: 15,000 m2

The main problem during the execution of the project was the small square storage yard, they analyzed the problems and then come up with improvements using lean methods and the results are shown in the figures below.

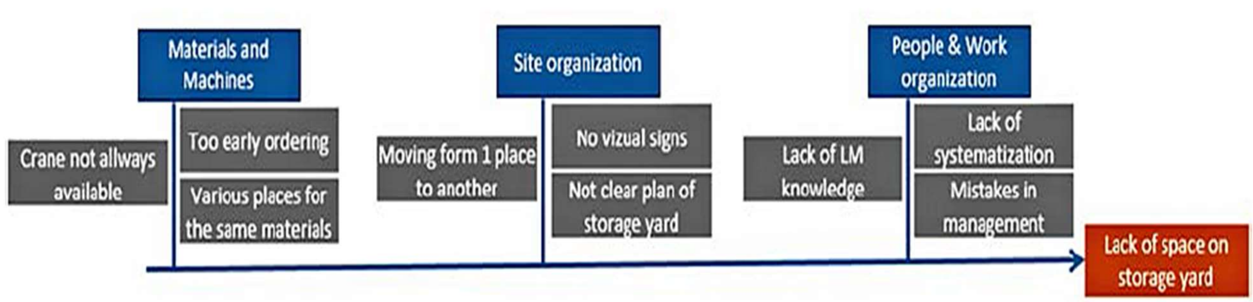

Figure 17 Observed problems in the storage yard. Source: (Nowotarski, Paslawski, & Matyja, 2016).

Figure 18 Results of implementation Lean methods for improvements. Source (Nowotarski, Paslawski, & Matyja, 2016).

Table 2 Lean methods used for improvements. Source: (Nowotarski, Paslawski, & Matyja, 2016).

Improvment methods	Expected effects	Expected impact	Measured impact
Just-In Time	-More available place on construction site	High	High
	-Savings on material transportation	Medium	Low
5S Method-	-Money savings -around 3000 PLN/month	Medium	High- 3782.50 PLN /month
	-Improvment of H&S	High	Medium
	-Quicker acces for materials	High	High
	-Less "in-site" transportation	High	Medium
Other storage options	-More available place on construction site	High	High
	-Quicker acces to reinforcement	Medium	Medium

3.5. Techniques and Methodologies

Lean construction and Six Sigma concepts as any other concepts are supported by techniques, methodologies, and tools to help in carrying out the implementation process. The author will explain in this part the major techniques and methodologies in a way that supports the aim of this research.

3.5.1. Lean Work Structuring (LWS)

Lean work structuring is a way to define the objective of a specific project from a lean point of view, the same applies in construction as there is a possibility to breakdown the project to define value assets and waste possibilities (Ballard, Tommelein, Koskela, & Howell, 2002). Figure 19 shows the idea of lean work structuring.

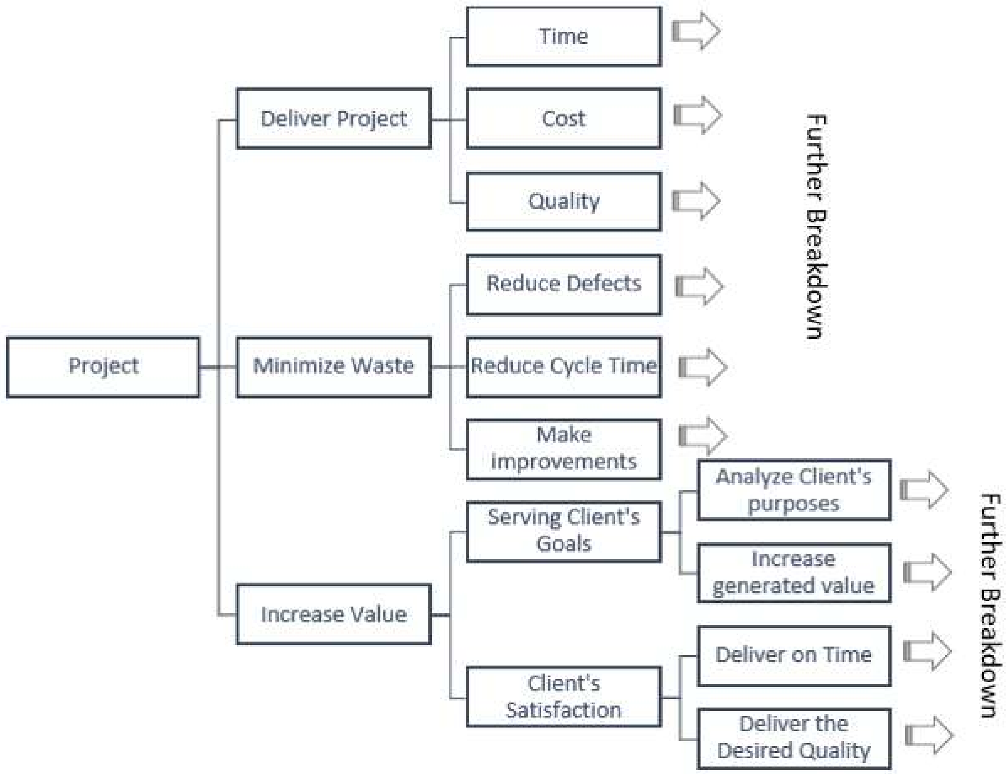

Figure 19 The concept of LWS. Adapted from: (Ballard, Tommelein, Koskela, & Howell, 2002).

The goal of creating the LWS is to determine the lean practices to be carried on in the project and the effect of each practice on the lean goals set for the project, the LWS can be linked to OBS, therefore, each practice is linked to the responsible person to follow up and control during the project lifecycle.

3.5.2. Pull Planning

Pull is the concept of executing according to the downstream works of a construction project, construction projects traditionally rely on the concept of push which means execute whatever is ready. Pull planning is a technique used to plan the flow of activities and information based on the request of downstream work, considering the possible risks affecting cost, time and quality by ensuring the involvement and collaboration between all parties in the project development. The process of pull planning encourages the needs for (HEERY, 2015) and (Tiwari & Sarathy, N.A.);

- defining clear portions of work
- considering just in time execution

- leveling of resources
- optimizing activities buffer time
- eliminating the chance of over processing
- most of all eliminating the possibility of waiting of redundancy by ensuring a continuous smooth work flow.

3.5.3. Takt-Time Planning

“Takt” is a German word that means “beat” which stands for the unit of time required to produce a product against the rate of time same product is required (Frandson, Berghede, & Tommelein, 2013), Takt-Time planning works in parallel with the last planner system, the aim of this technique is to create an efficient environment that suits the practices of the last planner system, Takt-Time creates a construction workflow while the last planner system is responsible about stabilizing and controlling the flow (Frandson, Berghede, & Tommelein).

The concept of Takt-Time is to organize the work of the construction trades by creating a workflow among construction zones where no trade clash with others and the work of each trade is completed within the planned duration (Theis, Tommelein, & Emdanat, 2017).

The application of Takt-Time lays under six main components; data gathering, zoning, trades workflow, trade productivity, workflow balance, combining all in a master schedule (Frandson, Berghede, & Tommelein, 2013).

Figure 20 Takt-time schedule template. Source: (Theis, Tommelein, & Emdanat, 2017).

- The x-axis represents the time scale

- The y-axis represents the project zones
- The colored boxes are the activities carried out; each color represents a different trade.

Some details and practices must be considered to ensure that the Takt-Time planning and implementation is carried out efficiently (Theis, Tommelein, & Emdanat, 2017);

- Divide the project into zones to avoid clashes and to help in creating a work flow
- Create work groups for each trade
- Estimate durations of each task based on the established work groups productivity
- Create a logical construction work sequence
- Optimize the groups workflow to avoid clashes and waiting times
- Workshops and meetings to ensure the whole process is clear for everyone.

The two major goal achieved from Takt-Time planning are;

- Tasks Synchronization by increasing concurrency.
- Trades Coordination by predicting the work release.

These main goals are supported by ideas to help in reaching them as illustrated in figure 21;

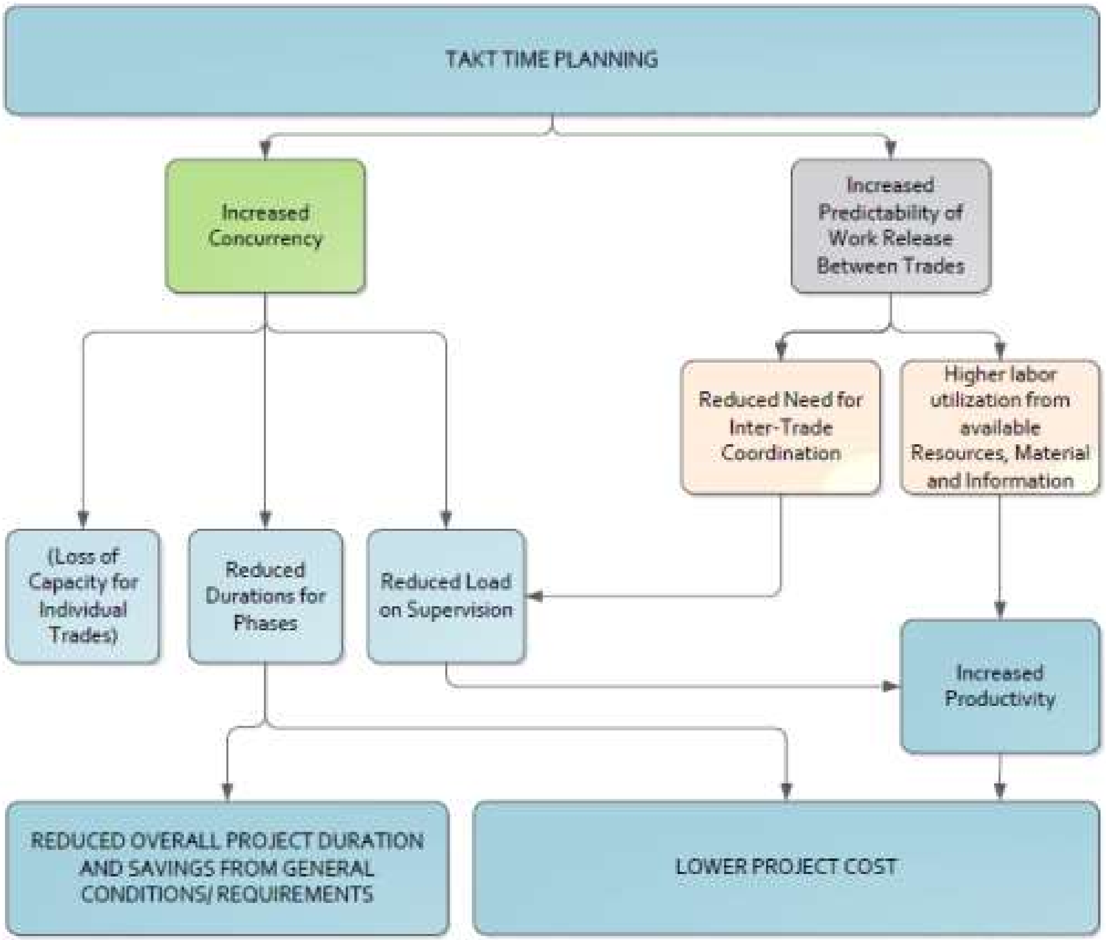

Figure 21 Benefits from applying takt-time planning. Source: (Theis, Tommelein, & Emdanat, 2017).

3.5.4. Last Planner System

The term last planner represents the actual individuals executing the near-term works on site based on the plans and lookahead schedule, the idea of last planner system is to involve the on-site responsible person for activity execution in the planning stage, this will provide a clear vision about what, when and how the activities will be executed. Also, it will simplify monitoring and acting in case any deviation from the original plan occurred (Ballard, Tommelein, Koskela, & Howell, 2002). Figure 22 explains the conceptual process of last planner system.

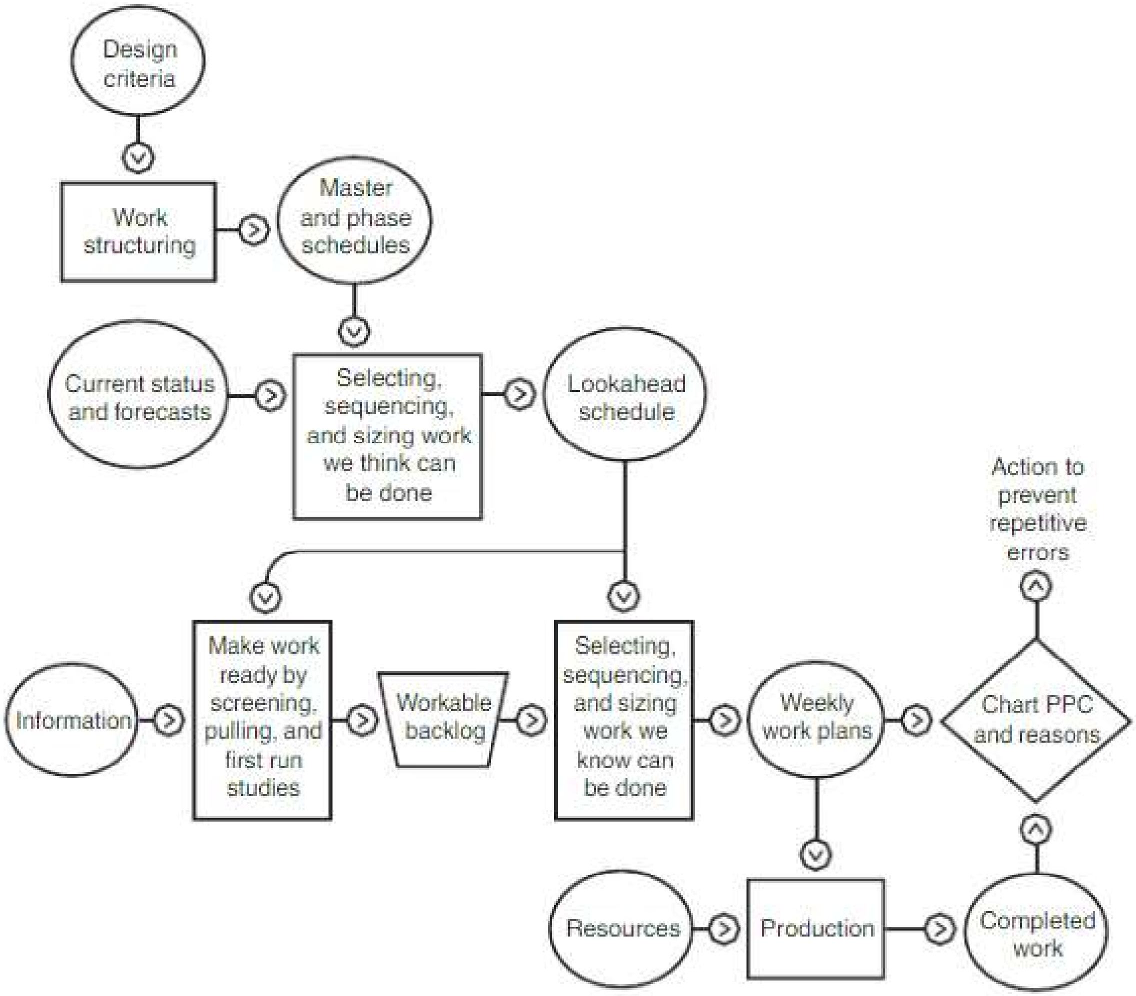

Figure 22 Last planner system. Source: (Ballard, Tommelein, Koskela, & Howell, 2002).

The process of LPS includes five main levels during the execution phase (Ebbs, 2017);

- **Should;** this level reflects all the task which were planned to be executed based on the master schedule.
- **Can;** this level reflects the tasks included in the lookahead plans. Constraints and requirements analysis is carried on the planned activities, therefore, lookahead plans are generated, where it includes all the tasks which are completely ready to be executed.
- **Will;** this level reflects all the tasks included in the daily and weekly plans generated by the directly responsible person as a commitment.

- **Did;** this level reflects all the tasks executed on site, by using monitoring tools the actual progress carried out on site is reported against the planned progress.

Learn; this level reflects the root cause analysis. Analyze the factors responsible for the deviation, discuss and review these factors and make sure it will be avoided in the future. Reschedule delayed tasks accordingly along with plans to recover the delay.

There are three main components of the last planner system; lookahead schedules, commitment planning, and learning (Ballard, Tommelein, Koskela, & Howell, 2002).

3.5.4.1. Lookahead Schedules

A detailed work for near-term planned activities usually within 6 weeks but it can be shorter or longer based on the project criticality. The aim of establishing the lookahead schedules are presenting a detailed workflow for near-term activities, carrying out analysis on the possibility of executing these works, establishing the operations required to execute these works, maintaining a backlog for the activities which are achievable, and carrying out constraints' analysis (Ballard, Tommelein, Koskela, & Howell, 2002).

Activities can be cross-checked using both constraints analysis and activity definition model as in figures 23 and 24. Constraints analysis is the analysis carried out on each activity in the lookahead plan, this analysis is to ensure that all constraints affecting the activities in the lookahead plan are defined, analyzed and a decision is made whether it is possible to eliminate the constraints or otherwise reschedule the affected activities.

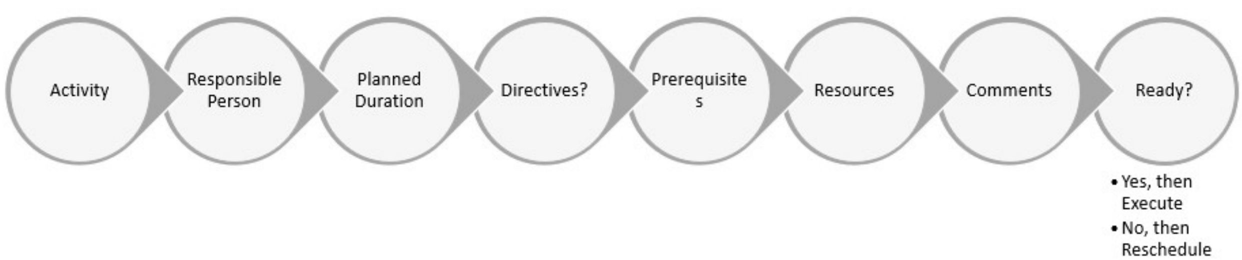

Figure 23 Constraints analysis. Adapted from: (Ballard, Tommelein, Koskela, & Howell, 2002).

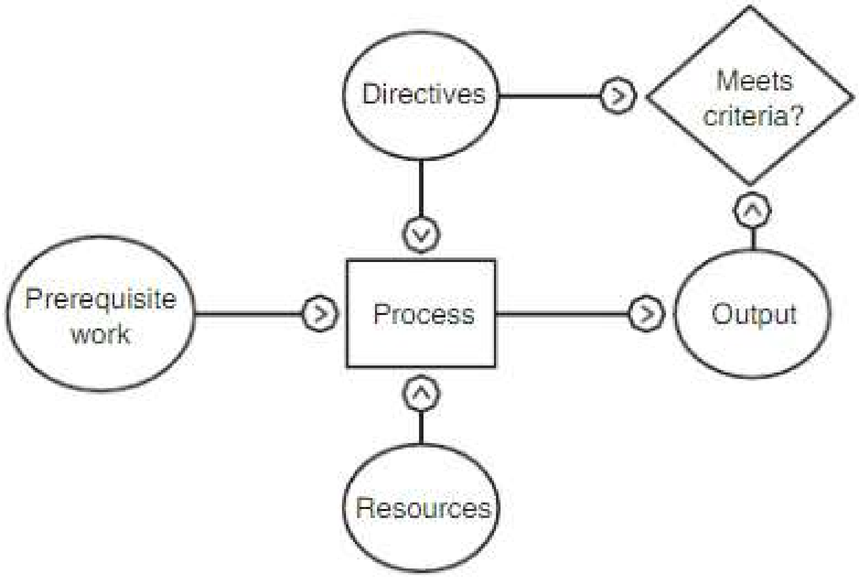

Figure 24 Activity definition model. Source: (Ballard, Tommelein, Koskela, & Howell, 2002).

3.5.4.1. Commitment Planning

Look ahead schedules are reflection of what should be done, but when we talk about commitment planning, we are talking about the actual work will be carried on, so is the work performed matching the work planned if yes, then no conflicts exist but if no, then it has to be analyzed and reasons have to be clarified (Ballard, Tommelein, Koskela, & Howell, 2002).

3.5.4.1. Learning

The whole idea of lean construction is based on defining the problems, modifying them, and learn from previous mistakes to avoid them from happening again. So, when a commitment is not met, reasons must be defined and analyzed, solutions must be established and learning workshops must be organized to spread awareness and ensure such mistakes will not occur again (Ballard, Tommelein, Koskela, & Howell, 2002).

3.5.5. Kaizen and 5S

5s is a term that represents the combination of 5 Japanese words which are Seiri (sorting), Seiton (set in order), Seiso (sweep), Seiketsu (standardize), and Shitsuke (sustain), it defines the concept of this technique which focuses on making and sustaining improvements during development (Ho, Cicmil, & Fung, 1995).

The basis of 5s technique handles the improvements that can be done during the execution of a product or an activity, the aims of this strategy is ensuring the removal of unnecessary resources; material, manpower, and equipment, develop the construction processes in a way to ensure elimination of inefficient practices, maintaining a workable clean environment and proper housekeeping of material and tools, generate regulations and standards for workers to follow in order to sustain these practices along time (Nowotarski, Paslawski, & Matyja, 2016).

The concept of Kaizen was first introduced in Japan in 1950 due to the management issues in the governmental sector. Also, in the Western company's kaizen concept has become common as it enhances continuous improvements that fit the company's needs. The word kaizen stands for, Kai (change) and Zen (good), so as a combination it reflects good changes. Kaizen main aim is to create a healthy atmosphere within an organization if implemented correctly (Gupta & Jain, 2014).

There are mainly six components to be carried on when applying the Kaizen technique; define the targeted area, key problems analysis, room for improvements, solutions, measuring improvements and setting up standards and guidelines (Gupta & Jain, 2014).

From the fact that there will be always room for improvements, Kaizen and 5s are continuous processes carried out through project lifecycle and through the organization lifecycle, those techniques have a great value but on the long run, by time, implementing those techniques within an organization will result in creating a healthy sustainable working environment.

3.5.6. DMAIC

The DMAIC which stands for Define-Measure-Analyze-Improve-Control is the major Six Sigma methodology. This methodology identifies variation in outputs as the problem; deviations from requirements, performance stability, and defects. Figure 25 illustrates the DMAIC model (Gitlow, Melnyck, & Levine, 2015).

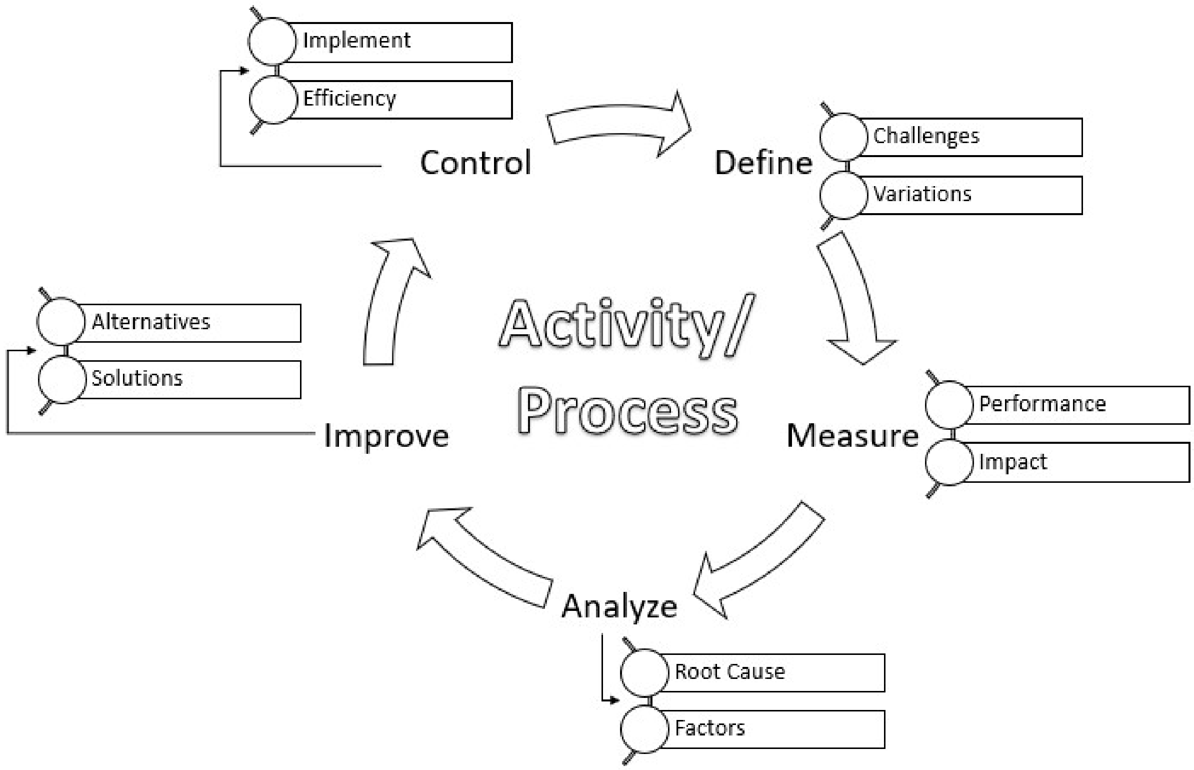

Figure 25 DMAIC Model. Adapted from: (Gitlow, Melnyck, & Levine, 2015).

The DMAIC methodology aims to allow for flexibility and iterative work, if necessary. The DMAIC is based on three main fundamentals (Gitlow, Melnyck, & Levine, 2015);

- The challenges are defined based on collected data, facts, and metrics. Typically, three key items are measured:
  - The output of the process (or product) that needs improvements
  - Process workflow of activities and items
  - Inputs; raw materials and information
- Project-based; each project has different challenges, concerns, and issues.
- The integration of tools and techniques varies from case to case.

4. Case Studies Related to Project Challenges

In this section, two major case studies where the author has been part of, related to two mega projects developed in Qatar will be analyzed, challenges will be defined and categorized based on the root cause using the DMAIC model (section 3.5.6.) in Six Sigma concept.

- **Define;** the author will define the project's challenges by comparing the original project scope of work, specifications, requirements, processes, and prerequisites with the facts reported in progress reports and minutes of meetings to determine the possible variations in quality, cost and time.
- **Measure;** the author after defining the possible challenges will measure the cost and time impact of each challenge using SPI and CPI to prioritize the challenges based on the impact.
- **Analyze;** the author will track down the root cause of each challenge occurred to define the related field of management. Root cause analysis is an approach used to define the origin of the challenges in order to rectify the faulty processes which led to the occurrence of these challenges.
- **Improve;** the author under section five will integrate lean construction and Six Sigma concepts to propose solutions and alternatives to rectify the processes related to the defined management field; therefore, overcome the occurred challenges.
- **Control;** the author under section five will integrate lean construction and Six Sigma concepts to propose control processes through the project lifecycle.

The process of applying the DMAIC model within the case study is identified in figure 26.

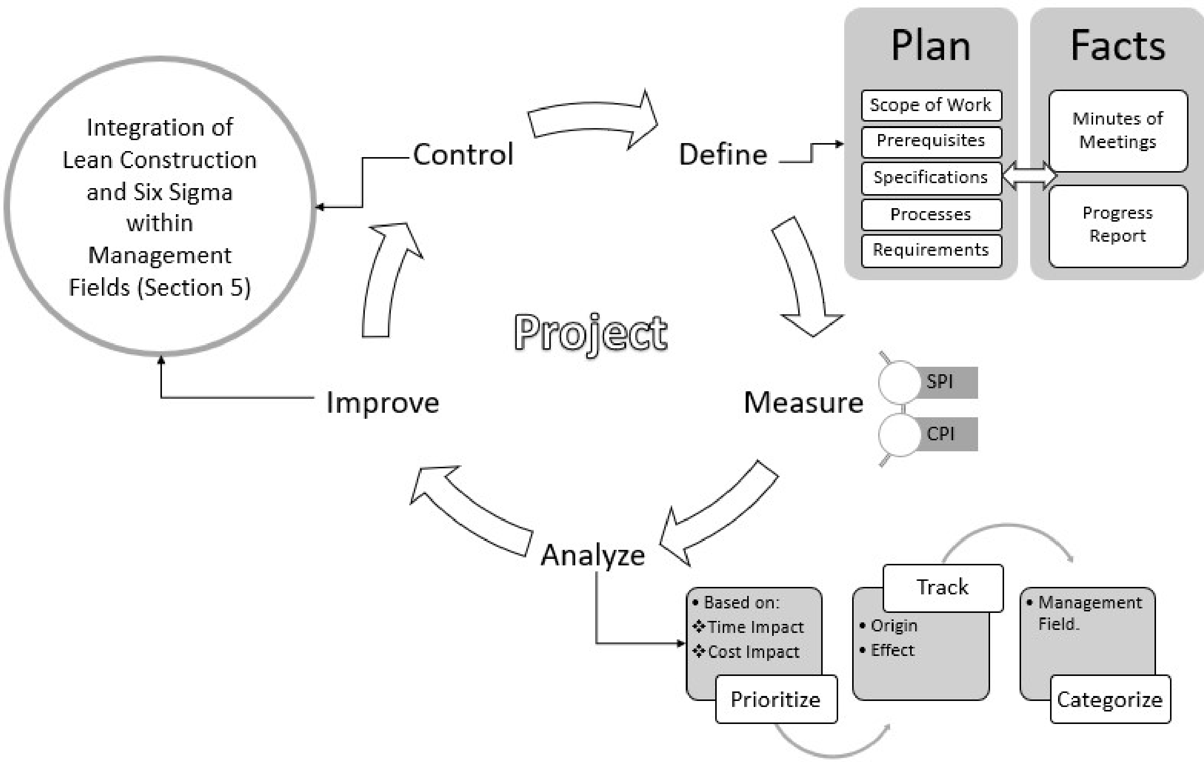

Figure 26 Process of DMAIC analysis within case study.

The reason for carrying out this analysis is to define project management fields where lean construction/Six Sigma is integrated for the best interest of project development.

4.1. Case Study 1: Development of Local Roads in RAHP

The project is located in an open desert on the western periphery of Doha, Qatar. Total project Area is 217 hectares and the objectives are to provide roads, drainage, and associated infrastructure to support a large residential development in Muaither District in West Doha. The tables presented below show the key dates related to project execution main events and the project's cost summary.

Table 3 RAHP project key dates.

Event	Date
Project Commencement Date	7th December 2014
Road Opening Permit Received on	23rd December 2014
Excavation Permit Received on	1st Jan 2015
Project Completion Date	5th December 2016

Table 4 Project cost summary.

Item	Amount in Qatari Riyal	Amount in Euro
Contract Value	544,991,076 QAR	136,247,769
Advanced Payment	54,499,108 QAR	13,624,777

The scope of work is divided into four major categories; earthworks, road works, drainage networks and supply networks as presented in figure 27.

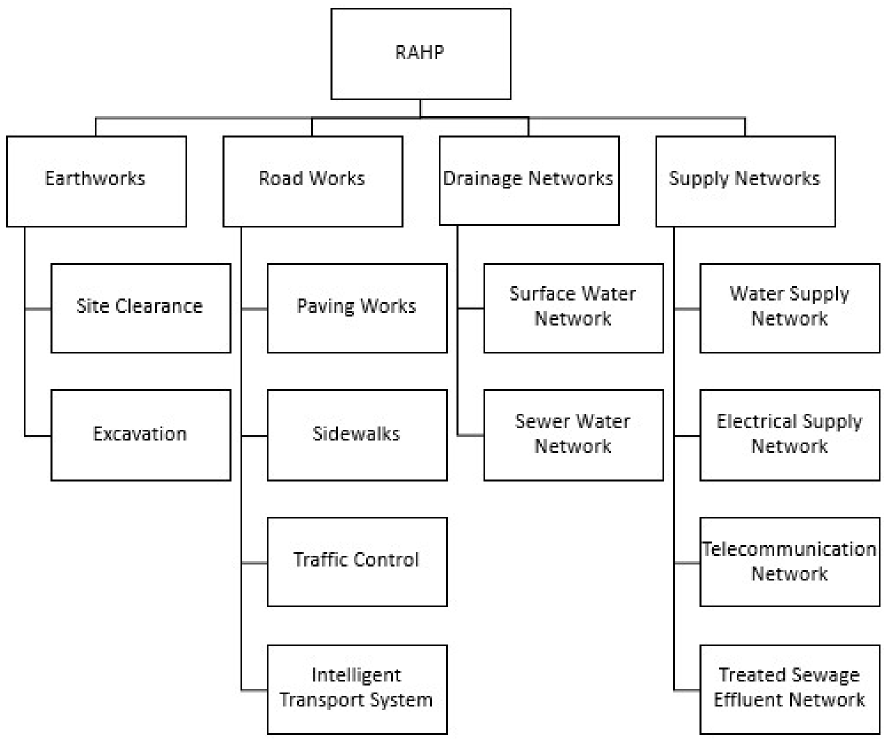

Figure 27 RAHP Scope of work.

During the execution phase of the RAHP project, slippages from the baseline schedule have been noticed, the monthly progress S-curve as of end of June 2016 is presented in figure 28, it shows the deviations that the project progress faced during the execution, these deviations have been analyzed and the author found out that baseline schedule itself is inadequate for monitoring purposes as well as the project faced many problems and challenges during the execution, due to these challenges project was almost on hold as there were no work open fronts; therefore, this has led to severe delays in all construction packages within the project. All challenges have been identified in table 5 and related to each package.

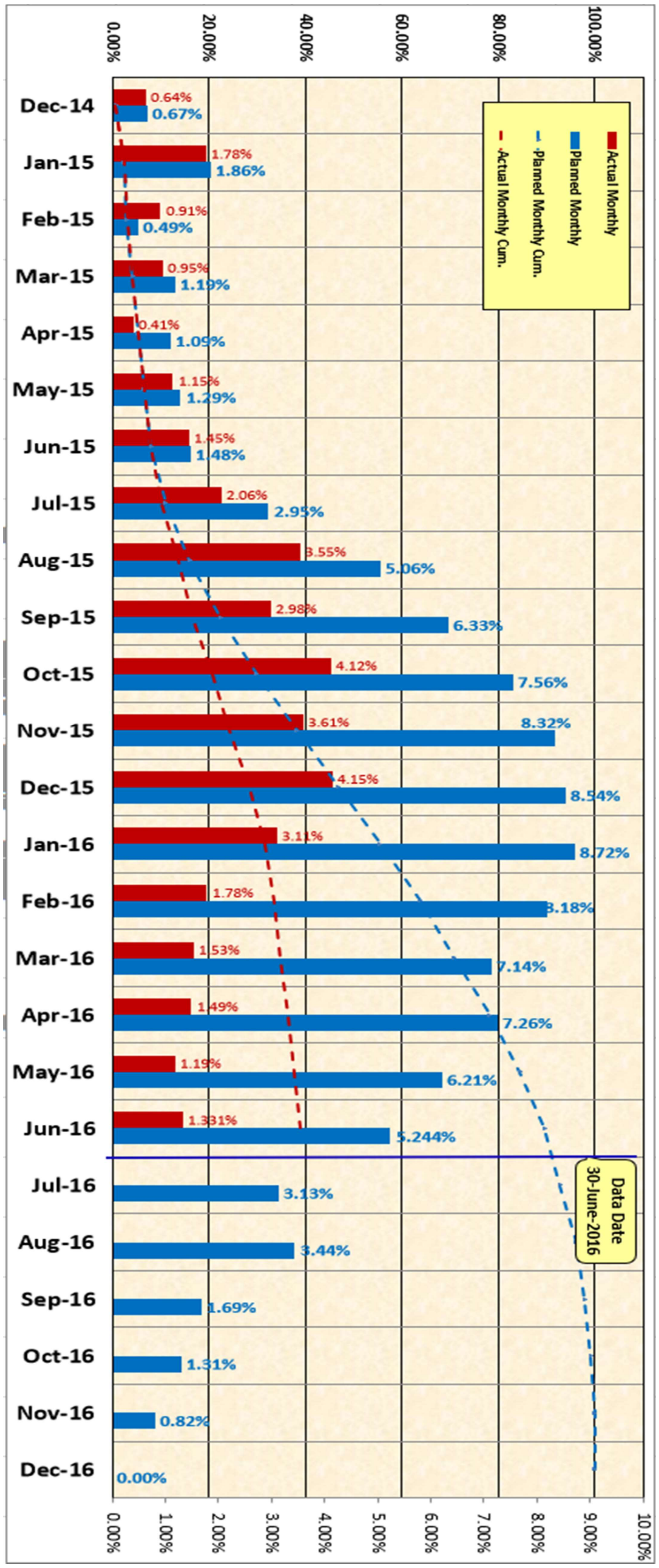

Figure 28 RAHP Progress S-Curve June 2016. Source: (Bataineh, 2016).

Table 5 RAHP project's problems during execution.

Source	Problems
Construction Works	• Late receival of road opening permit & excavation permit • Conflicts with local residentials • Slow rates in work execution • Storage area is compacted
Planning Package	• Faulty scheduling sequence between sewer water network and surface water network. • Improper productivity rates were considered while planning • Inadequate manpower allocation on site
Earthworks	• Amount & type of excavated material dose not match the BOQ • Continuous Equipment Breakdown • Change in specification from QCS 2010 to QCS 2014
Sewer Water Drainage.	Design issues; • The discrepancies between the existing levels and designed ones. • Revised manhole schedule and diameter.
Treated Sewage Effluent	Change in specifications; fittings inside the chambers to be changed from HDPE to DI fittings. DI fittings are a long lead material; requires long time of fabrication and delivery.
Electrical Supply Network	Revised IFC drawings.
Road Works	Design issues; • The discrepancies between the existing gate levels and designed ones. • Revised Cross Section due to relocation of Gullies that Clash with Electrical Corridor.

	• Revised Pavements Details. • Junction grading planes (Grading Layout). Change in specifications; • Change requirements from QCS 2010 to QCS 2014. • Site instruction to change the street lighting laminations to LED.
Surface water Drainage Network	Design issues related to; • Revised gully schedule • Revised IFC Drawings Due Gully Relocation Clash with Electrical Corridor • discrepancies between the existing gate levels and designed ones • Change in material filler specifications from limestone to gabbro

From table 5, the author categorized all the challenges faced during the execution process into six main management fields based on the root cause, table 6 presents the author's findings related to project challenges.

Table 6 Management field categorization based on root cause.

Field	Root Cause	Problems
Knowledge and Communication	• Preparation of permits, documents & specifications • External; Improper coordination with stakeholders • Internal; Miscoordination between project participants	• Late receival of road opening permit & excavation permit • Conflicts with local residentials • Amount & type of excavated material dose not match the BOQ

Planning and Scheduling	• Planning tools & techniques • Planning analysis	• Faulty scheduling sequence between sewer water network and surface water network. • Improper productivity rates were considered while planning
Design	• Mistakes during design • Client's additional requirements • Design coordination • Scope management	• The discrepancies between the existing levels and designed ones. • Revised manhole schedule and diameter. • Revised IFC drawings.
Construction Supply	• Material Analysis • Delivery Schedules • Material storing & handling	• Continuous Equipment Breakdown. • Storage area is compacted.
Construction Site	• Inadequate monitoring & control process • Workers skills and knowledge • Execution methodology	• Slow rates in work execution • Inadequate manpower allocation on site
Quality	• Change in regional standards • Value analysis • Improper quality control during execution	• Change in specification from QCS 2010 to QQCS 2014 • Revised Pavements Details.

		• Site instruction to change the street lighting laminations to LED. • Change in material filler specifications from limestone to gabbro

4.2. Case Study 2: Development of MDP4

Msheireb Downtown Doha development project phase four (MDP4) is located in the area of Msheireb in the heart of Doha, Qatar. The project consists of the development of 14 structural buildings for multi-purpose uses with a six-floor shared basement underground. The proposed facility phase 4 is intended to provide world-class, state-of-the-art facilities. It is also intended that phase 4 achieve the Leadership in Energy and Environmental Design (LEED) US Green Building Council Rating System “GOLD” rating level when completed. The scope of work for this contract is to supply, procure, install, construct, Test, commission and guarantee the main works for phase 4.

Phase 4 was divided into zones according to the location breakdown structure as presented in figure 29.

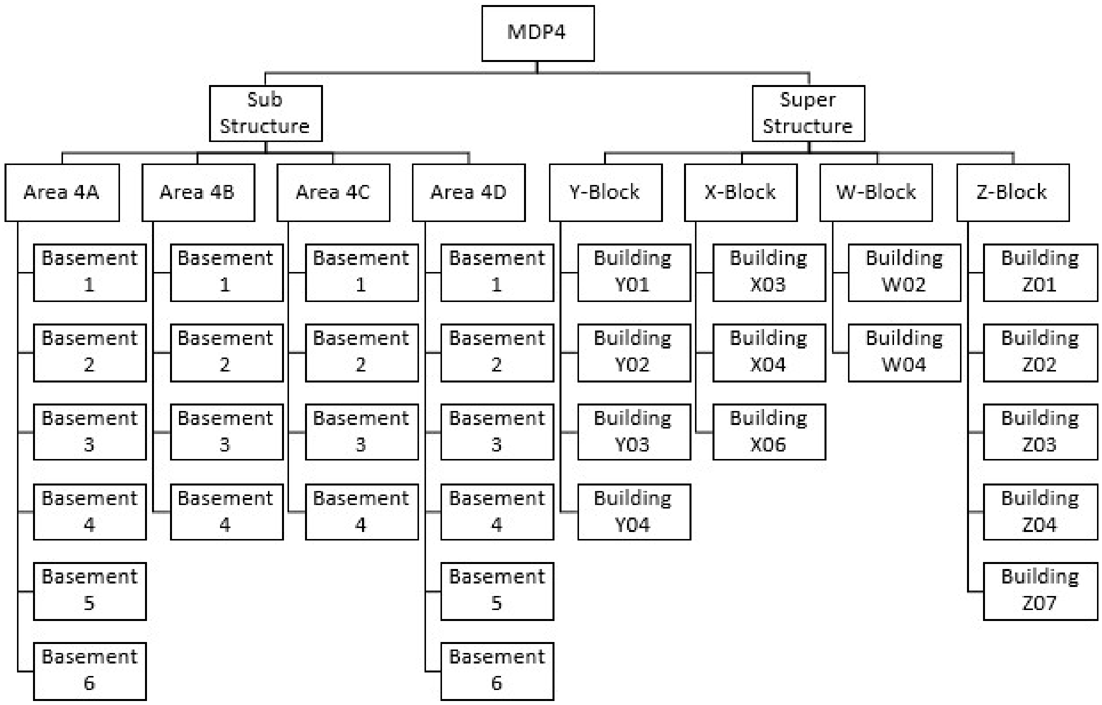

Figure 29 MDP4 Location breakdown structure.

The scope of work is divided into four major categories; civil and structural works, architectural works, MEP works, and landscape works as presented in figure 30.

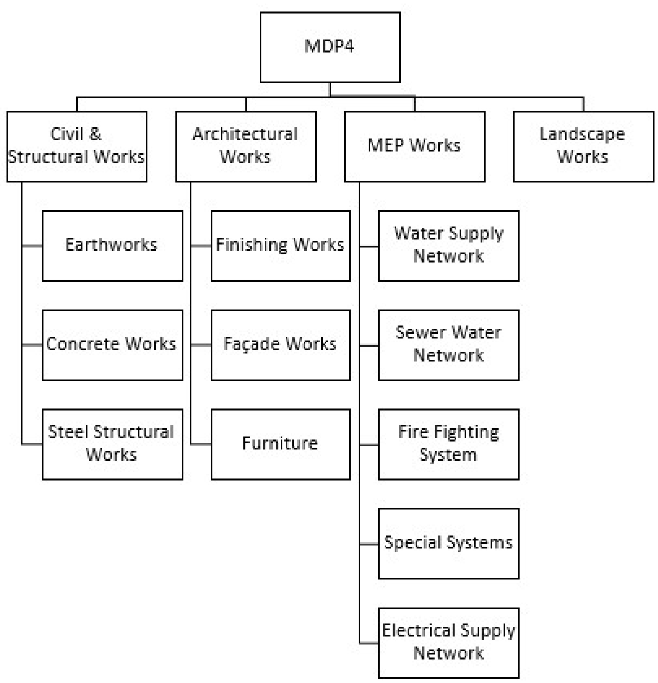

Figure 30 MDP4 scope of work.

The project is planned to be delivered according to the defined milestones in table 7.

Table 7 MDP4 project milestones.

Sec.	Milestone	Date
	Project Commencement Date	11th December 2016
01	Completion of Substructure works Area 4A	20th July 2018
02	Completion of Substructure works Area 4B & 4C	18th September 2017
03	Completion of Substructure works Area 4D	15th September 2018
4A	Completion of Superstructure works for Buildings Y01 & Y02	16th January 2019
4B	Completion of Superstructure works for Buildings Y03 & Y04	16th January 2019
05	Completion of Superstructure works for Buildings X03	14th March 2019
06	Completion of Superstructure works for Buildings X06	3rd September 2019
07	Completion of Superstructure works for Buildings X04A & X04B	11th July 2020
08	Completion of Superstructure for Buildings W02 & W04	8th September 2019
9	Completion of Superstructure for Buildings Z07 (Base Build)	11th November 2018
10	Completion of Superstructure for Buildings Z01 & Z04	12th March 2020
11	Completion of Works related to all Access roads within phase 4	15th November 2018
12A	Completion of Works related to Metro Entrances 2 & 3	22nd July 2018
12B	Completion of Works related to F/Ex 11/12/17/18, M-Plant Rm-B3/Egress Corr. to Entrance 2, Vent/Ex Shaft-M-Plant	18th September 2017
12C	Completion of works related to Fireman Access in Building. Z04 up to level 2	14th November 2017
12D	Completion of works related to Chilled Water system up to and through Metro Box	19th February 2018
	Project Completion Date	10th July 2020

Information related to project cost and the cost of scope changes as the end of May 2019 is presented in table 8.

Table 8 project cost summary.

Item	Amount in Qatari Riyal	Amount in Euro
Original Contract Value	2,295,726,000.00	573,931,500
Scope Changes	-547,594,825	-136,898,706
Modified Project Value	1,748,131,175	437,032,794

During the execution phase of the MDP4 project, it can be noticed from progress reports that severe slippages in progress from the baseline schedule occurred, presented in figure 31 is the monthly progress S-curve as of end of May 2019, the curve shows the deviation of the actual progress from the planned progress where it started in April 2017, these deviations have been analyzed based on project reports, minutes of meetings, official letters, and facts during execution, where the author found out that the project faced many reason and challenges during the execution, then he defined six major fields and related the major problems to. Challenges identified and categorized by the author are presented in table 9.

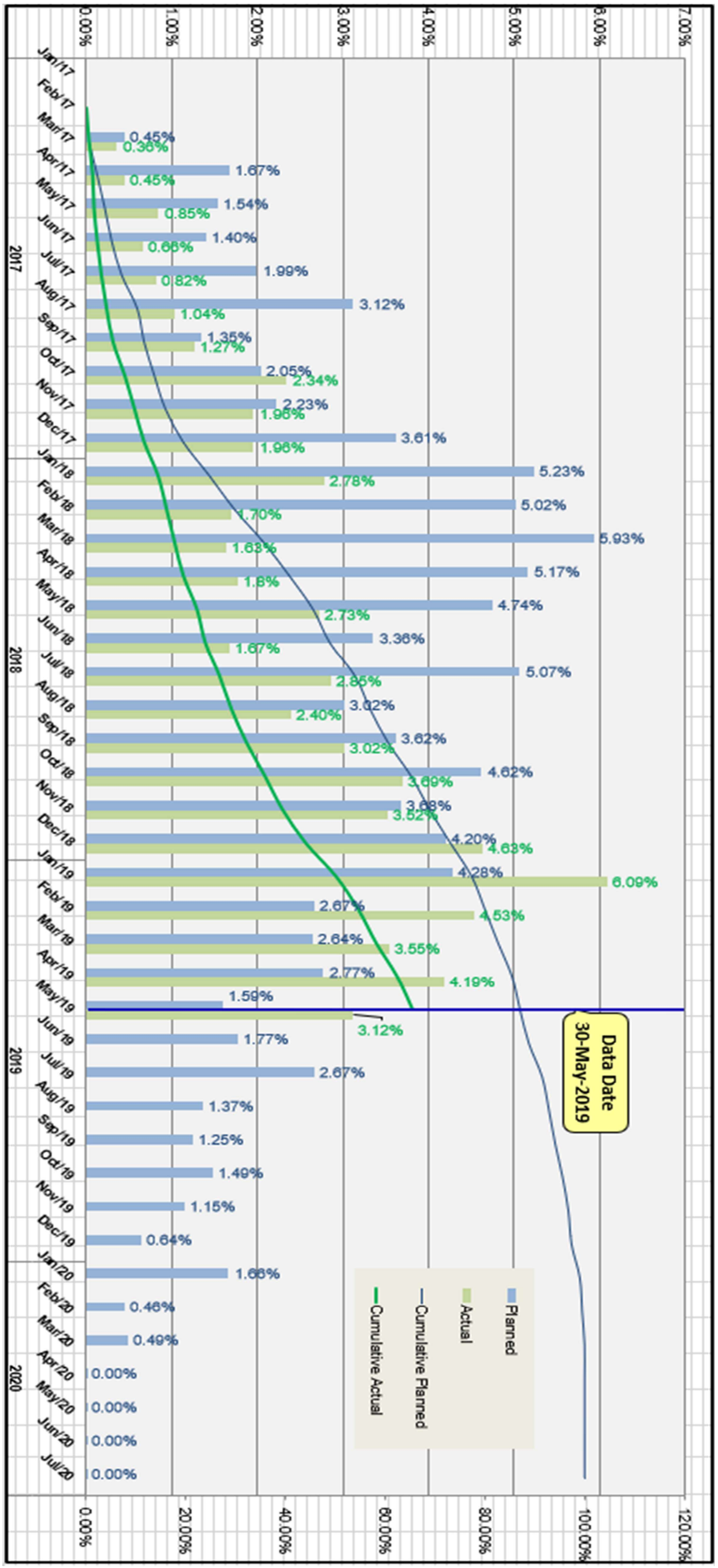

Figure 31 MDP4 progress S-curve May 2019. Source: (MDP4 Planning Department, 2019)

Table 9 RAHP Project's problems during execution.

Source	Problems
Contract	• Inadequate breakdown of BOQ items, preliminaries and provisional sum. • Contract agreement signature is not finalized due to the conflict about some terms. • Additional/amendment scope of work.
Planning	• Impossible deadline and milestones • Improper productivity rates were considered while planning • Inadequate manpower allocation on site • Interface with Qatar Rail project and possible negative impact on MDP4 works/milestones. • Miscoordination between TQ, MP and Qatar Rail
Project's Drawings & Specifications	• Revised IFC Drawings • Approval of LEED Consultancy • Delays in reply to submitted RFIs. • Approval of method statement and related MARs • Uncoordinated IFC Drawings between MP and Qatar Rail
Cashflow	• Deductions in contract original value due to scope amendments. • Delay in monthly approved payments • Client refused to pay material delivered into stores • Liquidity damages impact
Construction	• Site access point 2 is blocked by Qatar Rail. • Misalignment of rebar couplers on site. • Shortage or unavailability of material; where no alternatives available locally. • Safety concerns • Fatality case on site

	• Release of work from civil department to MEP department • Clashes between work groups • Limited labor skills and knowledge

From table 9 assisted by carrying out the root cause analysis the author categorized all the challenges faced during the execution process into six main management fields, table 10 presents the author's findings related to project challenges.

Table 10 Management Field Categorization based on Root Cause.

Field	Root Cause	Problems
Knowledge and Communication	• Preparation of contract documents • External; Improper coordination with involved stakeholders who interact with project execution; QP • Internal; Miscoordination between project participants TQ, MP & Contractor	• Inadequate breakdown of BOQ items, preliminaries and provisional sum. • Contract agreement signature is not finalized due to the conflict about some terms. • Interface with Qatar Rail project and possible negative impact on MDP4 works/milestones. • Miscoordination between TQ, MP & Qatar Rail • Uncoordinated IFC Drawings between MP & Qatar Rail • Delays in reply to submitted RFIs. • Release of work from civil department to MEP department

Planning and Scheduling	• Phase & milestone definitions • Cash flow analysis • Work flow analysis • Resource assignment	• Impossible deadline and milestones • Improper productivity rates were considered while planning • Inadequate manpower allocation on site • Delay in monthly approved payments • Liquidity damages impact
Design	• Design value analysis • Identification of objectives and goals • Design coordination	• Additional/amendment scope of work. • Misalignment of rebar couplers on site. • Revised IFC Drawings • Uncoordinated IFC Drawings between MP and Qatar Rail • Deductions in contract original value due to scope amendments.
Construction Supply	• Material availability in the market • Delivery Schedules • Material storing and handling	• Client refused to pay material delivered into stores • Shortage or unavailability of material; where no alternatives available locally.
Construction Site	• Construction methodologies	• Site access point 2 is blocked by Qatar Rail.

	• Construction practices • Logistics • Workers behaviour	• Safety concerns • Fatality case on site
Quality	• Value analysis • Quality control during execution	• Approval of LEED Consultancy • Approval of method statement and related MARs

4.3. Findings from Case Studies

While analyzing both case studies and the challenges developed through the execution of the project, the author noticed that each challenge resulted from poor management practices during the early stages of project development, therefore six main management fields were identified as the origin of these challenges based on DMAIC analysis carried on, these fields are;

- Knowledge and Communication Management
- Planning and Scheduling Management
- Design Management
- Supply Management
- Site Management
- Quality Management.

In the next section, the author aims to adopt lean construction and Six Sigma techniques in the defined fields to propose modified processes that support eliminating the occurrence of similar challenges during execution.

5. Integration of Lean Construction and Six Sigma in Project Management

In previous sections, the author's shed light on project management aspects, concerns, and goals, in addition to the concept of lean/Six Sigma and their different techniques. In this section, the author will try to integrate lean/Six Sigma management techniques for the purpose of improving project management practices.

Based on the findings of section two and four which identified the possible major challenges that project management faces, and the techniques of lean construction/Six Sigma identified under section three, the author in this section defined six major fields where lean construction/Six Sigma techniques can be implemented and desired results are achieved;

- Lean knowledge management
- Lean design management
- Lean planning and scheduling management
- Lean supply management
- Lean site management
- Lean quality management.

Lean vision focuses on two major aspects, the value of things and the elimination of waste, in the construction projects value is presented by the quality and the design of the project, while waste is presented by all practices that consume resources and do not generate any value.

The idea here is to reflect the client's objectives, goals and constraints into a design with a defined quality aspect and both the design and the quality reflect the project value, based on the desired quality both cost and time factors can be optimized and determined as explained in figure 32.

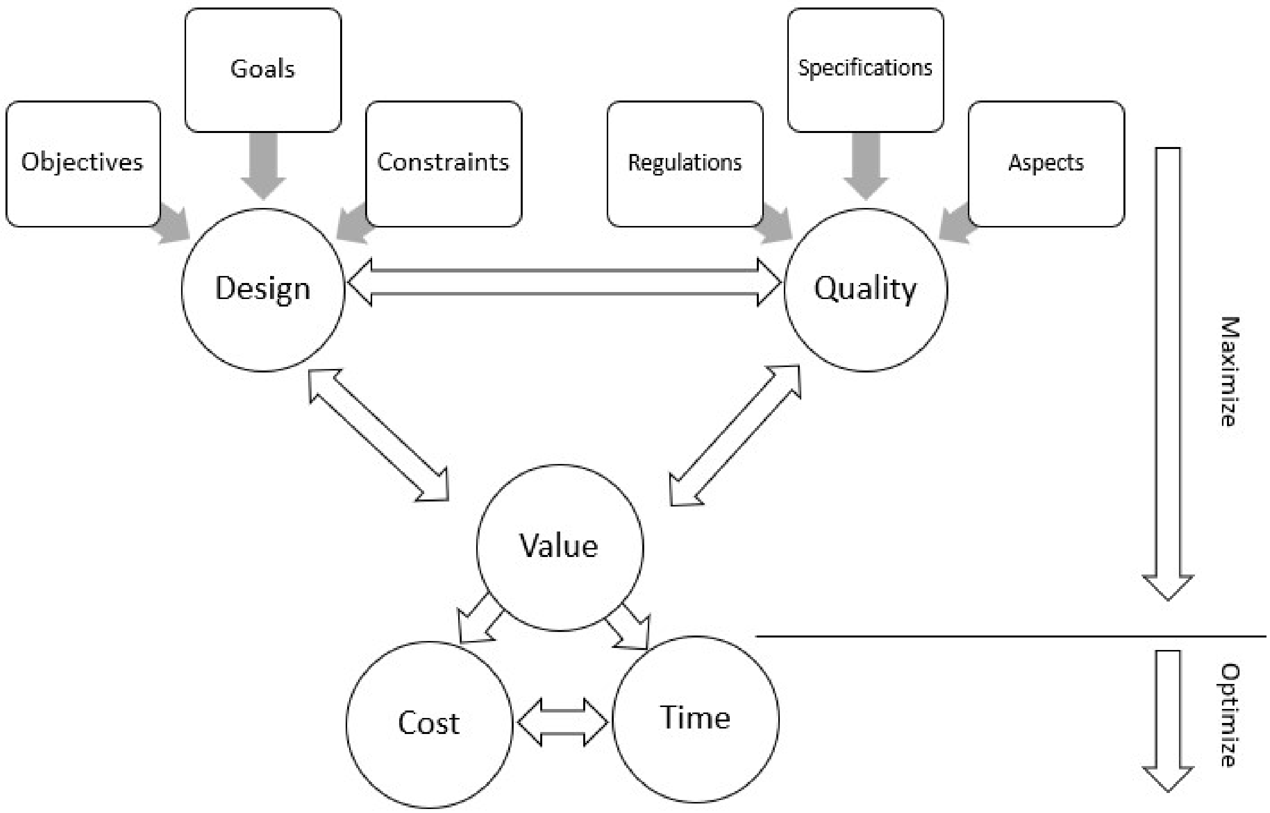

Figure 32 Lean value management vision.

In order to maximize the project value, lean techniques must be adapted in all project aspects that influence project value, adopting lean techniques in these aspects must be in-line with project pillars quality, cost and time. Project value is determined at the early stages of development; therefore, the following three major fields are identified for enhancing project value; Lean knowledge management, Lean design management, and lean quality management.

On the other hand, minimizing waste is the second aim of lean management, it starts at the early beginning of project development. In the design phase minimizing waste is considered by ensuring that the design considered the project constructability and the methodologies of execution, while in planning optimizing the resources and ensuring an optimum workflow during execution is the key to eliminate the waste possibility. Finally, during the execution phase where both practices and logistics are the main factors that affect waste generation. The overall process reflecting the concept of minimizing waste is presented in figure 33.

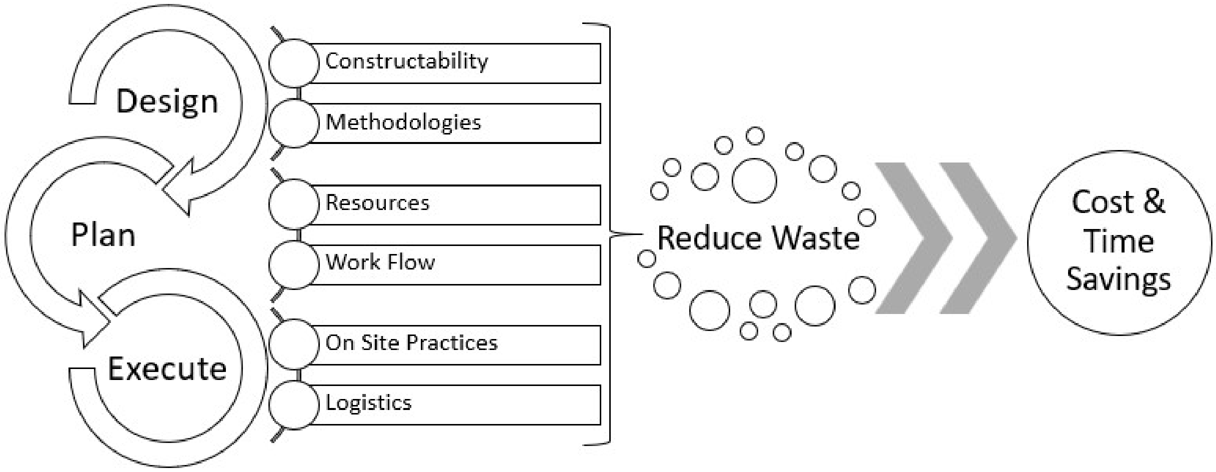

Figure 33 Lean waste management vision.

Starting with the design management, as identified constructability and construction methodologies are the key factors of controlling waste. Decisions made during this phase will shape the processes during execution, therefore, defining the strategies to be in-line with the detailed design is the core principle of waste reduction. Moving to the planning management, the combination of both; pull planning and takt-time planning is the way to achieve optimized project resources and smooth continuous workflow, achieving that will eliminate the waste related to costs of extra unnecessary resources and the possible delays resulted from disruptions and clashes in the workflow. Finally, whatever is planned and designed should be reflected correctly on site, from here comes the necessity of rectifying execution processes using Kaizen, 5S, and DMAIC techniques.

5.1. Lean Knowledge and communication Management

Knowledge understanding and sharing is one major aspect during any project development when we mention the term knowledge in project development, we are talking about all types of information, techniques, skills, and experience required to develop the project. Knowledge management is the art of generating the required knowledge, share it with involved participants and make sure it is been implemented for the benefit of project development.

The major aspects of lean/Six Sigma must handle in this field are;

- **Knowledge clarity;** all related information, processes, and techniques are clearly defined and concerned parties are aware of it.
- **Knowledge efficiency;** all related information, processes, and techniques are evaluated and efficient to cover the needs and requirements.
- **Knowledge understandability;** all related information, processes, and techniques are defined and understood by concerned people. The utilization of this knowledge should be clear.
- **Communication methods;** transferring knowledge efficiently among project participants.
- **Coordination;** all participants are working in-line with each other, no conflicts in interests.
- **Satisfaction and feedback;** the client and other stakeholders are continuously aware and satisfied during the development.

Lean knowledge management is a term that fits within the lean concept, basically means ensuring the required information is delivered to the concerned people in the right form and at the right time. The challenges here are defining what is the required information, who is the concerned parties, in which form the information should be delivered to ensure it is understandable and applicable, and when exactly is the information required (Rooke, Sapountzis, Koskela, Codinhoto, & Kagioglou, 2010).

Lean knowledge management is a continuous process aims to support the fulfillment of client's requirements through project development by; (Rooke, Sapountzis, Koskela, Codinhoto, & Kagioglou, 2010);

- Continuously define the client's requirements through the project life cycle
- Generate optimized design based on these requirements
- Identify the required knowledge to feed the process of project development
- Implement Knowledge; deliver this knowledge to responsible parties of project development processes in the right form and at the right time
- Evaluate the client's satisfaction and get feedback.

Lean knowledge management as stated earlier is a continuous process through the project life cycle where the client's requirements are always defined, achieved and evaluated, figure 34 explains the cycle of lean knowledge management.

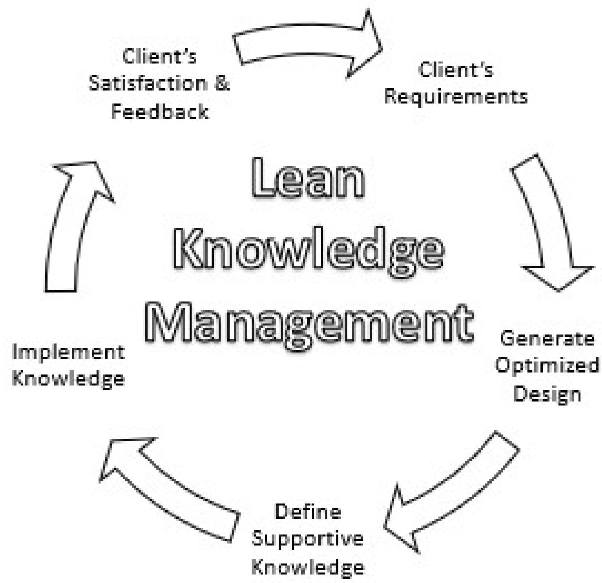

Figure 34 Lean knowledge management cycle.

The client's requirements are defined based on the objectives, each objective can be defined in different ways, Lean/Six Sigma targets the aspects that add extra values to the project by categorizing the client's requirements into basic and value-added. These can be categorized carrying out the statistical approach of Six Sigma using the DMAIC model;

Define; the client's requirements based on the main objectives, continuous communication with stakeholders, analyzing the future market to advise the client with future opportunities.

Measure; define measurement methods to reflect the value percentage of each requirement from the overall project value. Measure the value percentage of each requirement and prioritize them in a log according to the value percentage.

Analyze; the log of requirements is analyzed by defining the supportive knowledge and processes to fulfill it. Once they are defined; areas of improvement can be determined.

Improve; in this process, the integration of Kaizen is a great tool to define the possible improvements, reflect them into ideas and practices, evaluate the value added on the project considering these improvements, and communicate with the client and other concerned stakeholders for feedback and approval.

Control; Once improvements are defined and approved, related information should be delivered to the concerned parties to implement. These improvements should be monitored and controlled to ensure it is carried on as defined.

The advantages of lean knowledge management can be summarized under the following points:

- Achieve maximum project value by ensuring all parties on board are efficiently participating in the project development
- Achieving maximum value possible by cooperating improvements within requirements and processes.
- Avoid misunderstandings and mistakes generated due to miscoordination and/or miscommunication
- Avoid waste generation; time delays and cost overruns that might occur due to faulty knowledge management
- Client’s satisfaction when all requirements are early addressed and covered.

5.2. Lean Design Management

The process of design in construction is a mental activity, where inputs are transferred to generate a detailed plan to support the development of a certain project. Inputs are the requirements of the Client; objectives, constraints, and goals. The output of this process is a combination of models, drawings, plans, specifications, aspects, and regulations which represents the basis of the project and must be followed during the project implementation phase (Tilley, 2005).

Design management is the process of defining strategies required for carrying out the design process, coordinating between participants involved in the design generation to ensure strategies are followed and evaluating the generated design to ensure all client’s needs are covered.

The major aspects of lean/Six Sigma must handle in this field are;

- **Design adequacy;** the functionality of the proposed design is in-line with the client's objectives and future expectations.
- **Design constructability;** value engineering should take part to analyze the best methodology to execute the project, therefore, reflect it in the detailed design.
- **The project scope of work;** all objectives, requirements, and specifications are covered in the detailed design.
- **Design coordination;** all participants are working in-line with each other to avoid clashes in design and/or errors in design.

Lean design management aims to ensure the adequate transformation of requirements into ideas, optimize the flow of information required to reflect these ideas into initial models, and ensure maximum possible value are achieved out from the design. Presented in figure 35 is the integration of lean design management in design sub-processes.

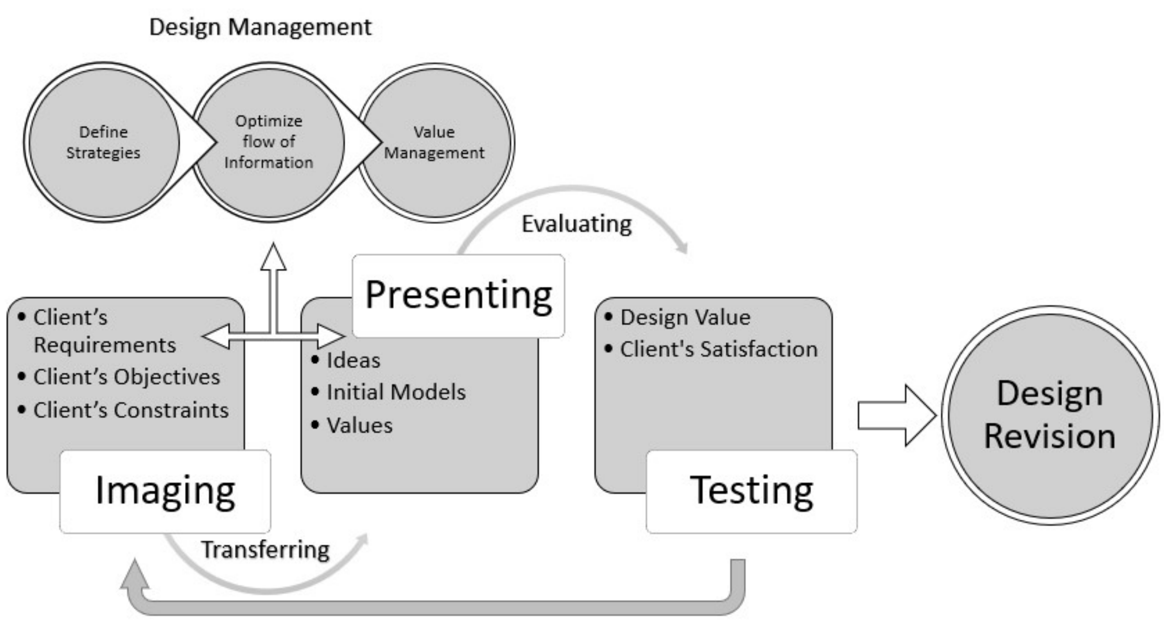

Figure 35 Lean design life cycle.

Lean/Six Sigma principles can beneficially serve the design phase and enhance the design management process by increasing the value of the generated design and reducing the possibility of waste generated through the implementation phase; cost, efforts and time. During the design stage, uncertainty level is extremely high and major decisions considered at this stage have a high-risk potential affecting the project implementation phase, therefore project failure. However, construction projects evolve over time and conditions change which create a conflict with the original plan and design, lean principle relies on creating a dynamic design concept which allows the project to adapt to these changes and avoid risks of project failure, this concept is achieved by creating a collaborative environment between participants in the design phase and ensuring the design is flexible and willing to adapt to possible risks.

Design value here also covers two major terms; project constructability and construction methodologies; both terms affect the process of project execution in relation to waste management, constructability as defined by Construction Industry Institute (1986) is “the optimum use of construction knowledge and experience in planning, design, procurement, and field operation to achieve overall project objective,” (Alalawi, et al., 2015), while The ASCE in 1991 defined constructability as “the capability of being constructed” and constructability program as “the application of a disciplined, systematic optimization of construction related aspects of a project during the planning, design, procurement, construction, test, and start up phases by knowledgeable, experienced construction personnel who are part of a project team. The program’s purpose is to enhance the project’s overall objectives.”

In other words, constructability is the concept of considering efficient construction methodologies mainly during the design phase, and followed up by proper planning and execution, in order to avoid execution risks, costs overrun and schedule delays which might cause project failure.

Lean management idea is involving the contractors in the design phase by the application of different contracting types, for example, aliens and design-build contract. The interference of the contractor at the design stage will help considering execution challenges, methodologies, and risks in the detailed design. Presented below in figure 36 explains the proper coordination and interaction among project parties to achieve an adequate and constructible design.

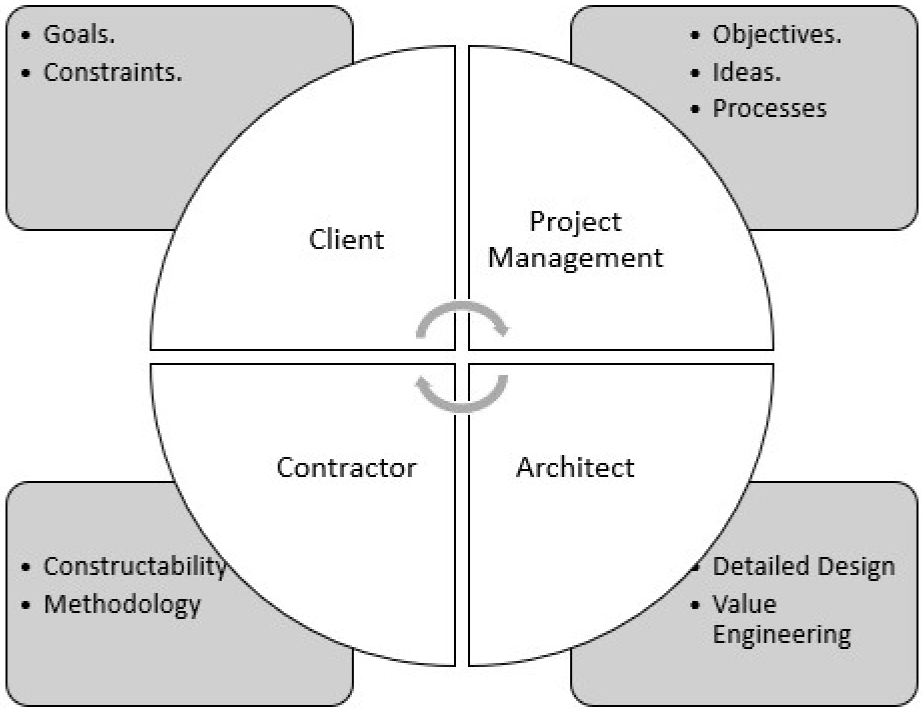

Figure 36 Lean design participants.

Benefits of the lean design management can be summarized under the following;

- Meet all project participants expectation
- increase design value and reduces project risks
- Reduce the chance of future changes in scope
- Eliminate design errors and mistakes.

5.3. Lean Planning & Scheduling Management

Planning is the art of defining efficient processes and methodologies to manage, execute and control the project through its life cycle, this involves assigning resources based on the project needs, estimating costs through the project life cycle, and defining the sequence and flow of work as well. Lean principles focus on increasing the project value and reducing the waste, as discussed in earlier sections, waste categories include the waste in resources which is the main output of the planning stage. During the planning stage, defining methodologies and workflow is the factor affecting the required amount of resources needed through project execution.

Scheduling is the process of reflecting the planned works into a group of tasks with defined resources, the sequence of work and costs. The output of this process is a master schedule that all parties involved will follow during the project execution for the purpose of monitoring and controlling.

The major aspects of lean/Six Sigma must handle in this field are;

- **Phases and milestones planning;** the stages of project development should be identified to support the aspects of quality, time and cost.
- **Resources;** optimum use of resources to avoid extra costs.
- **Cash flow;** positive cash flow should be maintained for both client and contractor to secure the funding during project development.
- **Workflow;** smooth continuous sequence of work should be planned to avoid delays from the unavailability of work fronts, clashes, and interruptions.
- **Execution monitor and control;** practices on site are in-line with the project master schedule. Deviations are defined, analyzed and reflected into revised schedules.

The aim of lean planning and scheduling management is to optimize the resources by ensuring a smooth continuous workflow is planned, this can be achieved by implementing the techniques of scope management, location-based planning, takt-time planning, pull planning considering cash flow analysis and resource leveling, and finally, ensuring proper monitor and control during the execution phase by implementing the last planner system technique. Figure 37 presents the idea behind lean planning & scheduling management.

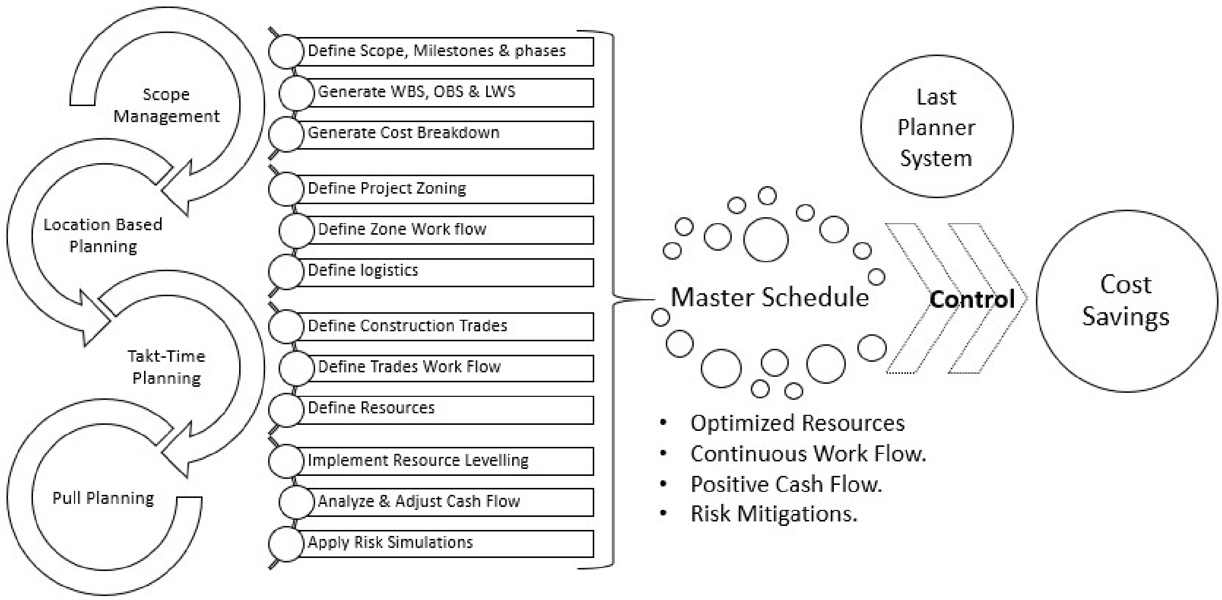

Figure 37 Lean planning and scheduling process.

5.3.1. Lean Scope Management.

According to the PMBOK scope management includes five major steps; identifying client's and stakeholders' requirements, reflect them into a detailed scope of work, generate a work breakdown structure, then cross-check the generated WBS with the requirements in order to verify the scope and ensure all requirements are addressed, finally, control the scope throughout project lifecycle (PMI, 2008). This process is presented in figure 38.

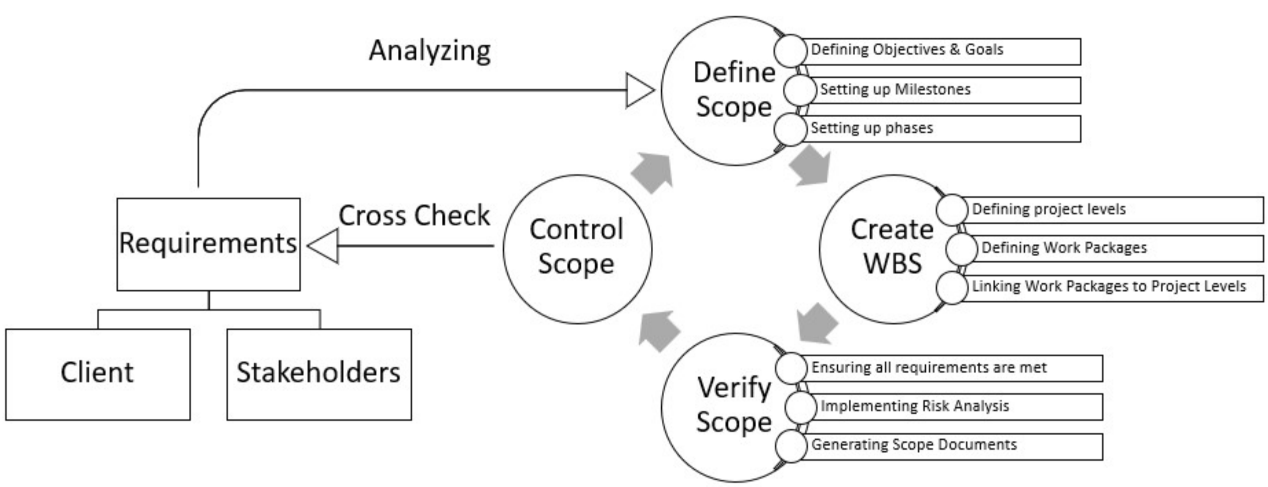

Figure 38 Traditional scope management. Adapted from: (PMI, 2008)

The aim of integrating lean principles in this process is to maximize the scope value and eliminate the possibility of waste generation in later stages. By integrating both OBS and LWS in creating WBS the following can be achieved;

- Determining the value of each work package and its effect on overall project value
- Determining the possibility of waste categories related to each work package
- Linking work packages to responsible participants.

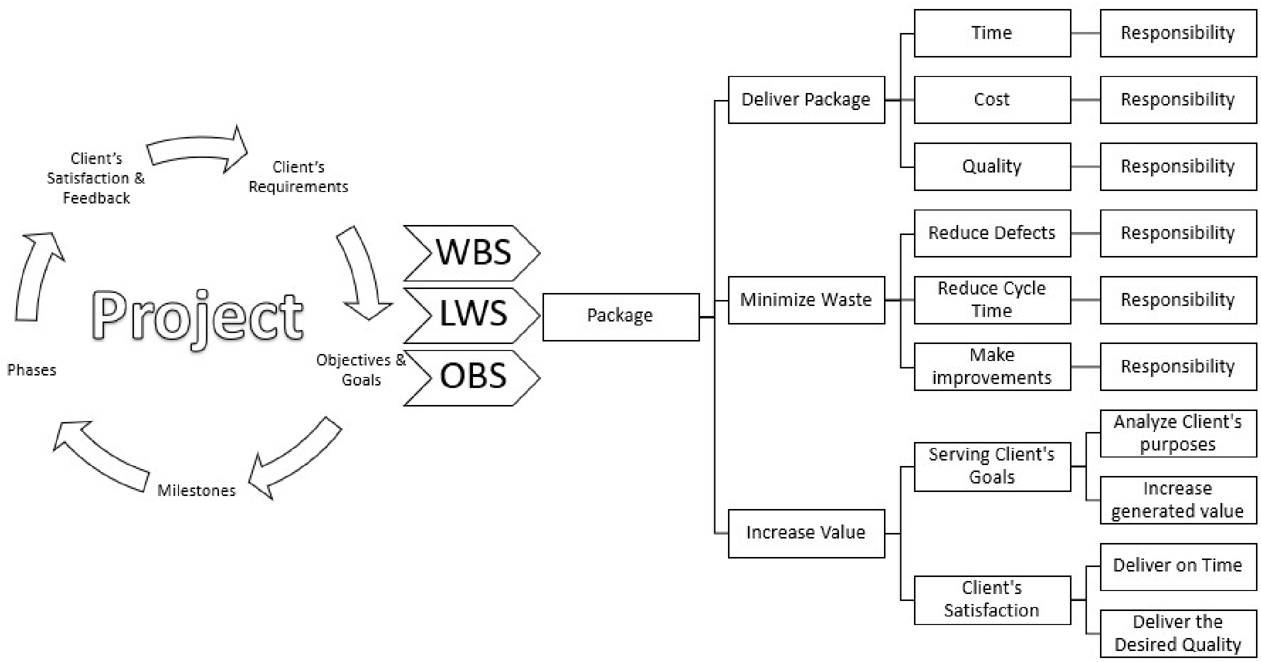

Figure 39 Lean scope management.

From figure 39 it is possible to define work packages where value can be increased, and waste can be minimized as well as the possibility of involving the responsible person in the verification process, specifically in risk analysis. Lean scope management influences the idea of minimizing the possibility of scope changes in later stages by ensuring proper value management during the planning stage, this will reduce the possibility of risks related to scope changes which have a severe impact on project budget and time.

5.3.2. Lean Scheduling.

The concept of lean scheduling is combining the following three techniques to generate a master schedule based on the outputs from the scope management process;

- **Location-based planning;** the aim is to generate a location-based workflow, therefore, avoiding interruptions and clashes among tasks.
- **Takt-time planning;** the aim is to generate a trades workflow represented by groups, therefore, define required resources for task execution and avoid clashes among trades.
- **Pull planning;** the aim is to optimize both resources and cash flow to ensure positive cash flow is maintained during execution.

Construction Projects are large scale projects with a lot of complexity, one way to simplify project development and planning processes is by breaking down the project into location chunks, this concept presented in figure 40 is known as Location breakdown structure (LBS).

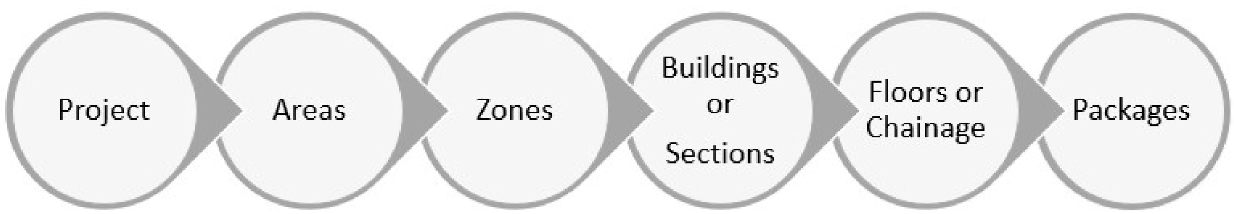

Figure 40 Location breakdown structure concept.

The purpose of dividing the project into location chunks is to achieve better planning, monitoring and controlling. location-based planning system defines location; as planning and control major unit, where workflow is based on locations. Creating a repetitive workflow through project different locations is the main idea, this will decrease the project complexity and dependencies among planned tasks. The term LBMS describes a planning technique involves the use of LBMS algorithm which depends on ensuring a continuous workflow of workgroups instead of individuals, replacing planning buffers with schedule buffers between tasks, and optimizing schedule resources (Seppänen O. , 2017).

LBMS application defines five major characteristics that form the idea of the concept (Seppänen, Ballard, & Pesonen, 2010);

- Generate a location breakdown structure
- Reflect project tasks, quantities, and resources on project locations
- Visualize the workflow using the line of balance planning technique
- Carry out risk management analysis and apply schedule buffers between tasks; space buffers and risk buffers.

Takt-time is a way to divide work packages into work trades assigned to workgroups. The process of integrating LBMS with takt-time planning is presented in figure 41.

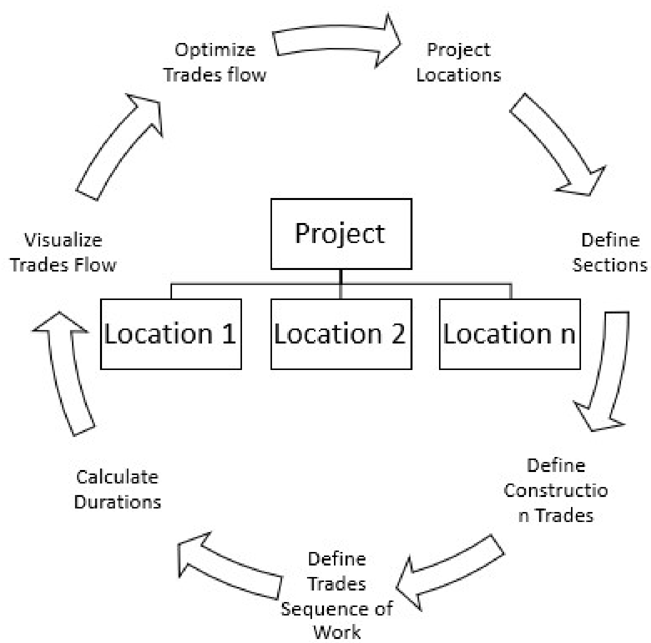

Figure 41 Integrating LBMS with takt-time planning.

This process can be achieved by defining the required tasks to complete a certain package in a certain location, tasks are repetitive among locations so, the workflow is defined on each location which reflects the sequence of work. Considering each workgroup has certain productivity; therefore, the duration needed to complete a specific work trade in a certain location can be calculated; duration in shifts is equal to quantity (unit) multiplied by group productivity (shifts/Unit). The next step after calculating durations is visualizing and optimizing the workflow per location by adjusting the number of work groups for each trade and divide locations into sections to avoid clashes between different workgroups. The process of applying takt-time in this phase is defined in figure 42.

Figure 42 Takt-time trade flow optimization process.

Cash flow is a major concern in construction projects, as most of the projects are funded by banks, clients must be able to secure liquidity throughout the project life cycle, this can be achieved by ensuring that the bank payments can cover the execution of works without the need to reserve extra liquidity for time intervals were cash-in is less than cash-out.

The concept of pull planning as covered under section (3.5.2.) is to plan the execution of tasks based on the downstream demand relying on the concept of just in time. The main idea here is to set the project cash flow as the downstream demand; where cash flow should remain positive during project development. Although tasks are scheduled based on the workflow, it is still possible to shift the scheduled tasks in order to optimize cash flow and resources. Cash-in is the payments from the funder, it usually follows certain guidelines and is paid upon completion of certain milestones; foundation works, structural works, MEP works, etc., cash-out is the expenses required to execute the project; payments for contractors, suppliers, etc., pull planning aim is to achieve a balance between cash-in and cash-out to eliminate the risks of project running in negative cash flow while maintaining the same productivity for construction trade groups.

Cash flow can be balanced by shifting the tasks using the integration of both location-based planning and takt-time planning with pull planning as presented in figure 43. The main target of this process is to minimize waste generated through the overuse of resources, the inefficient distribution of resources, and negative cash flow.

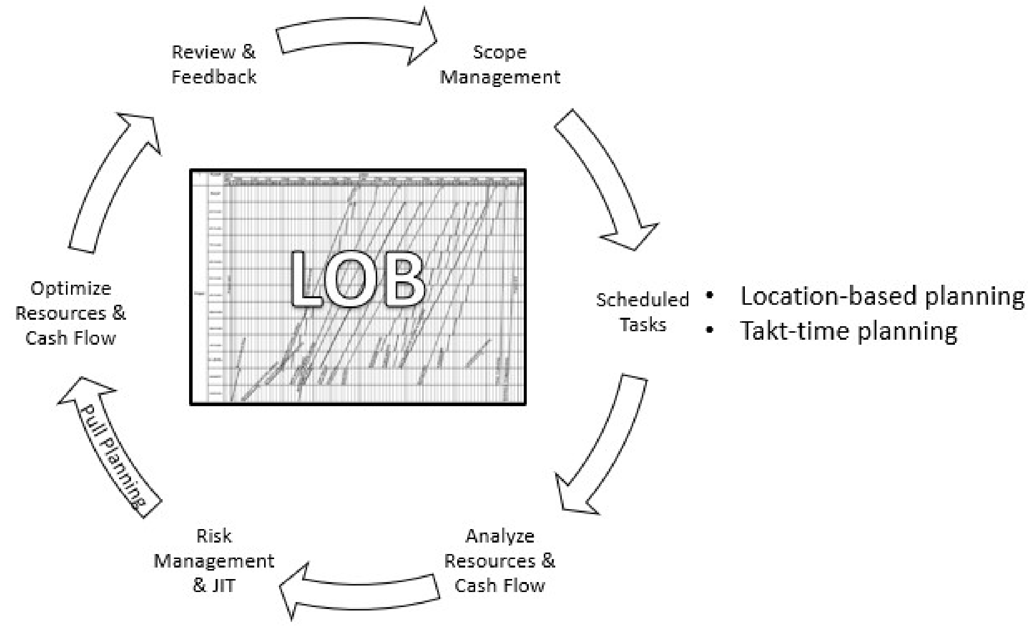

Figure 43 Integrating LBMS and takt-time planning with pull planning.

The Integration of the pull planning concept within project planning can be achieved following the major six steps defined in figure 44.

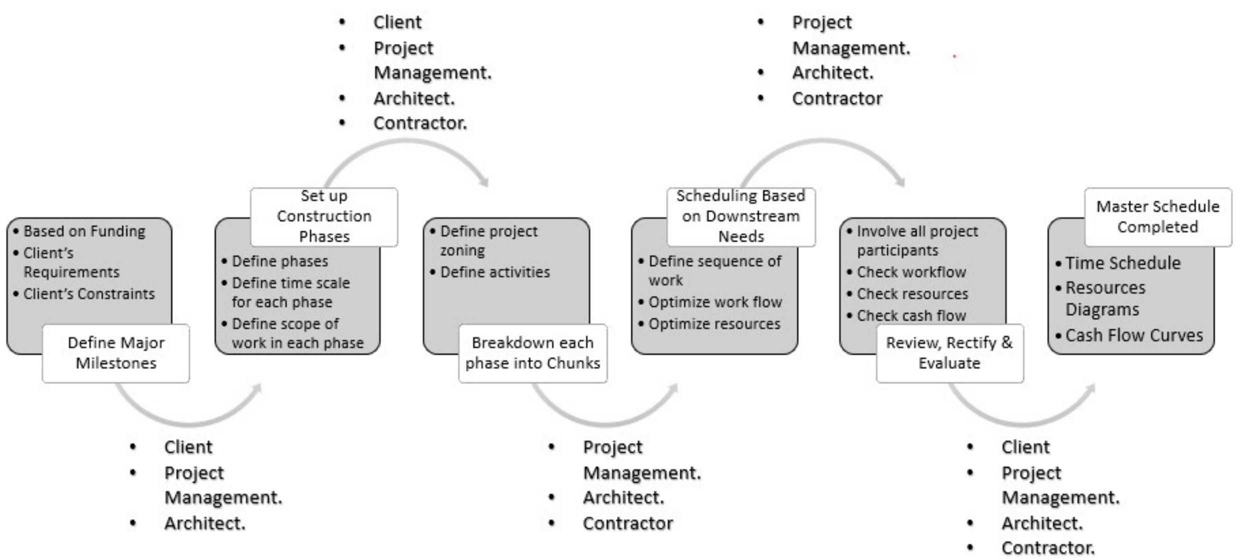

Figure 44 Pull planning process

From figure 44, the technique of pull planning gives more important aspects to focus on during scheduling other than the traditional focus which was only about the project duration and sequencing of work. Pull planning ensures the optimum use of resources during project execution while maintaining a continuous workflow without interruptions or clashes among different trades of construction. Also, it takes into consideration the project cash flow based on the funding, this will help the client to avoid running through negative cash flow during project execution. Last but not least, it ensures that all parties are aware of the schedule and the process of development to avoid any conflicts that might lead to delays and extra costs.

Figure 45 and Table 10 present the outcomes from an exercise of implementing lean scheduling on a set of activities using VICO software and the impact on cash flow.

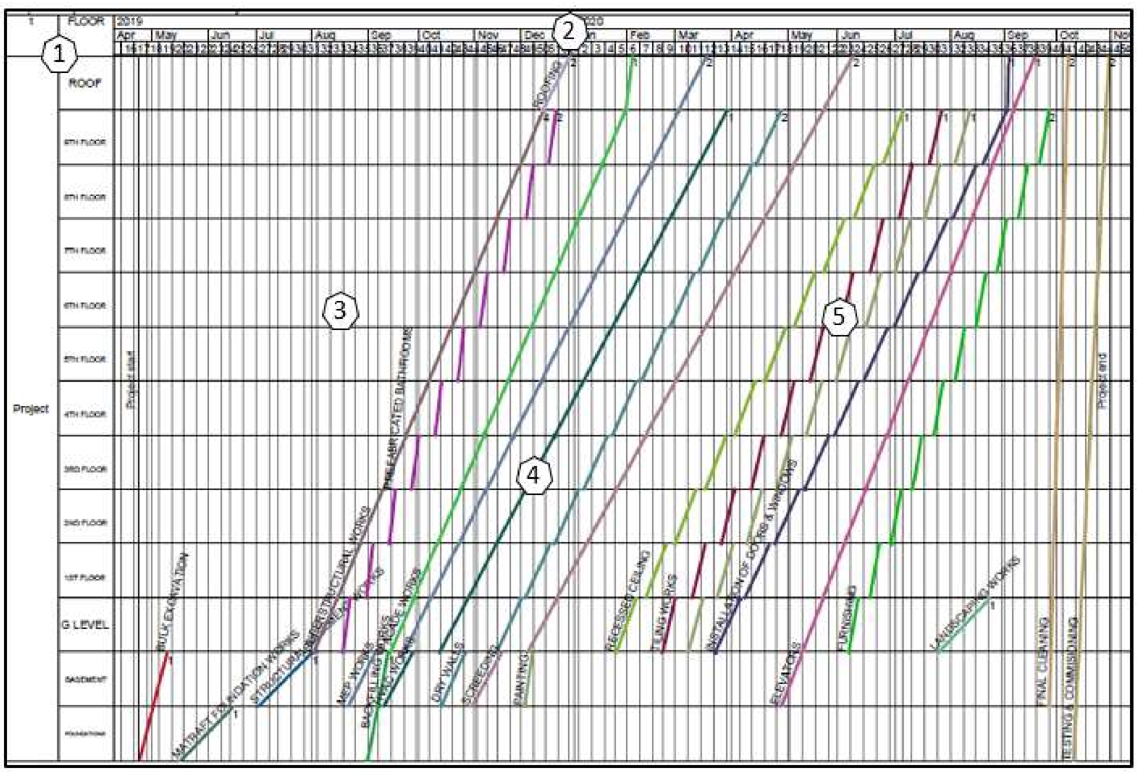

Figure 45 Location-Based Planning Using VICO

- No.1 Represents the location breakdown of the project
- No.2 Represents the timescale
- No.3 Represents the scheduled tasks window.
- No.4 Optimized Workflow.
- No.5 Interrupted Workflow.

Table 11 Traditional vs. Optimized cash flow.

Activity	Productivity	Duration (Days)		Resources (No. of Groups)	
		Traditional	Optimized	Traditional	Optimized
BULK EXCAVATION	0.45	11	11	3	3
FOUNDATION WORKS	2.50	21	21	5	5
STRUCTURAL BASEMENT WORKS	1.42	21	21	5	5
BACKFILLING WORKS	1.92	8	8	3	3
SUPERSTRUCTURAL WORKS	2.09	120	90	12	16
PREFABRICATED BATHROOMS	14.64	27	27	8	8
MEP WORKS	5.22	130	130	8	8
HVAC WORKS	3.13	125	125	5	5
DRY WALLS	0.75	106	106	6	6
SCREEDING	1.41	140	140	6	6
PAINTING	0.15	63	63	2	2
FAÇADE WORKS	0.67	96	96	4	4
ROOFING WORKS	0.96	21	10.5	2	4
ELEVATORS		100	100	SC	SC
RECESSED CEILING	0.27	54	81	3	2
TILING WORKS	0.17	34	51	3	2
DOORS & WINDOWS INSTALLATION	1.27	36	96	6	2
FURNISHING	182.40	75.4	38	3	6
LANDSCAPE WORKS	0.25	20	20	3	3

Month	Liquidity	
	Traditional	Optimized
Apr-19	2,315,333.60	2,315,333.60
May-19	2,300,355.00	2,300,355.00
Jun-19	2,284,839.60	2,284,239.60
Jul-19	2,164,439.60	2,163,239.60
Aug-19	1,958,299.40	1,949,724.60
Sep-19	1,509,491.70	1,481,194.60
Oct-19	865,538.80	750,717.10
Nov-19	52,990.70	3,597.10
Dec-19	(877,466.15)	1,714,683.58
Jan-20	(1,683,281.75)	1,117,958.38
Feb-20	476,617.07	742,617.38
Mar-20	457,754.97	854,023.74
Apr-20	234,869.33	802,329.34
May-20	(99,923.77)	505,421.19
Jun-20	176,188.92	155,264.15
Jul-20	(440,810.88)	(262,622.27)
Aug-20	(212,603.17)	208,396.73
Sep-20	(269,303.17)	(234,963.17)
Oct-20	-	-
Total Negative Cashflow	(3,583,388.89)	(497,585.44)
Percentage of Negative Cashflow	-46%	-6%

From table 11, we can see that the percentage of negative cash flow dropped from 46% to 6% only by optimizing the resources within the scheduled tasks.

The location-based management does not only include the process of planning and scheduling before execution but also extends to involve the interaction with last planner techniques during the execution stage to ensure proper monitor and control is carried out (Seppänen, Ballard, & Pesonen, 2010).

5.3.3. Lean Monitoring & Controlling - LPS

Project planning also includes the process of monitoring the actual progress of the project and controlling possible deviations that occur. Lean techniques ensure the proper implementation of the generated plan during project execution. LPS is the major technique that supports the concept of lean management during the execution phase, as discussed in previous sections; LPS is a continuous process that requires the involvement of the actual person responsible for executing the tasks on site; site engineer, site foreman, and supervisors. Involving the direct person responsible of the task execution will have a positive effect on execution progress, lookahead plans are generated on weekly basis and discussed with workgroups on daily basis in order to clarify the work required to be completed, analyze the constraints affecting the execution of the task, and report the concerns or conflicts that affected the execution of a certain task to the planners where they can revise and reschedule the plans accordingly. Actual progress is calculated against planned progress, deviations are highlighted and analyzed, recovery plans are generated accordingly, and lessons learned are discussed with participants involved to avoid similar problems in the future. The integration of LPS levels within progress monitoring and controlling is reflected in figure 46.

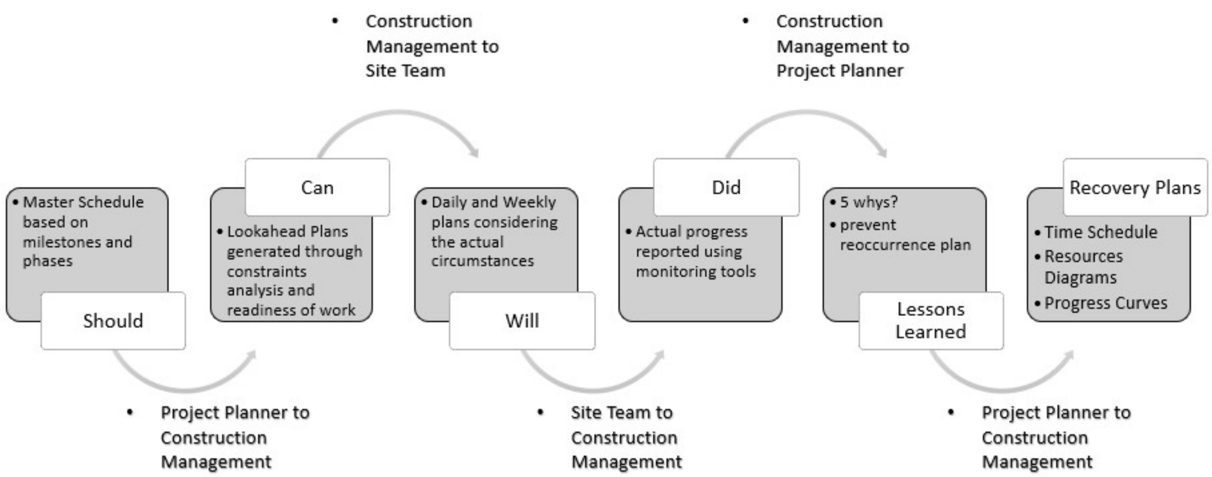

Figure 46 Integration of LPS levels in execution phase.

The main aims of using the LPS to support the master schedule prepared based on the lean planning and scheduling management are;

- Clarify planned works for site teams
- Ensure availability of the work fronts as per plan
- Report possible constraints in execution to the planning team
- Update the master schedule regularly to reflect the actual status on site
- Accurate progress reporting
- Revise the plans in case slippages or delays occur
- Define lessons learned from deviations and carry out workshops to avoid future conflicts.

5.4. Lean Supply Management

The primary goal of implying lean principles within the construction supply field is to increase the material value; reduce cost and increase quality, and reduce the material waste; surplus material, overhead costs and handling costs. Figure 47 presents the fields where lean principles react to enhance the supply field in construction.

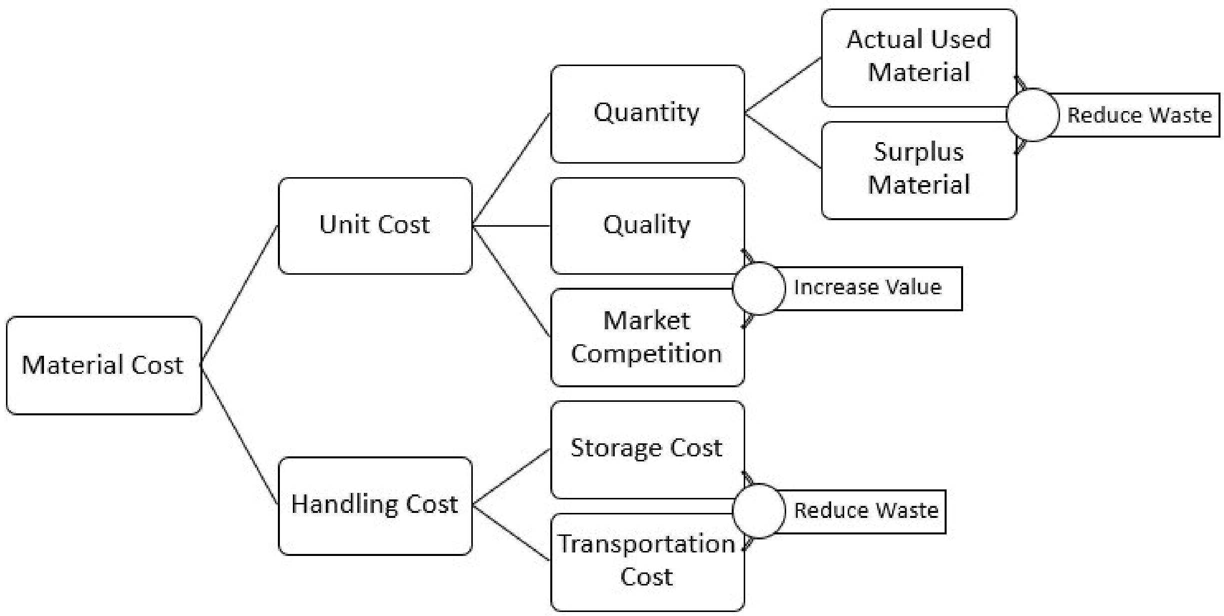

Figure 47 Integration of lean principles within construction supply.

The main three techniques in order to achieve lean principles through the construction supply process are; value analysis, Just in Time delivery and centralized supply unit. Combining these techniques through project development phases and specifically in the execution phase will result in increasing the project value and reducing waste.

5.4.1. Value Analysis

Material's value is represented by two terms; cost and quality, material's value are increased when you get the maximum possible quality for the lowest possible price. Material's quality is determined through the design phase, so implying a lean design concept should also consider studying the available material options that suit the project the most; quality and cost wise. On the other hand, the cost of material depends on many variables, the main variables that influence the material's cost are;

- The design aspects decided during the design phase based on the client's requirements.
- Execution methodologies planned based on material functionality.
- Market demand and supply which has a direct influence on the material unit price.

5.4.2. Just in Time Delivery

This technique is implemented during the execution phase in order to cut down project waste related to the supply process; costs generated from material overheads and handling, time consumed on storing and transporting material, and actual physical waste of material. The main idea is to establish a Just-in-Time delivery system linked to the site construction team directly where the material is ordered and delivered only when tasks are completely ready to be executed. In order to ensure the efficiency of this system, it must be linked with LPS as well, where material required is generated from the lookaheads schedules and weekly plans (Arbulu & Ballard, 2004). The concept of Just-in-Time delivery is explained in figure 48.

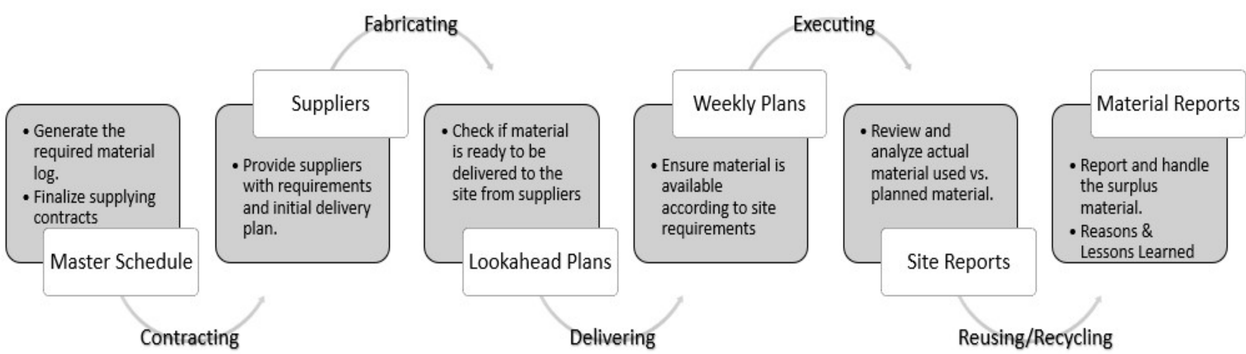

Figure 48 Integrating LPS with Just-in-Time delivery.

Implementing this process will have a positive impact on the project execution costs where;

- Cost savings resulted from reducing storage spaces
- Cost savings resulted from cutting-off unnecessary transportation costs
- Cost savings resulted from cutting-off overheads and handling costs
- Cost savings resulted from avoiding ordering surplus material
- Time savings resulted from extra material handling

- Time savings resulted from proper site management and logistics
- Cost savings resulted from reusing/recycling surplus material if any.

5.4.3. Centralized Supply Unit

The supply unit will be the link between site management in different projects within a certain construction firm with suppliers in the market, this will help in eliminating the extra overhead costs related to contracting, handling and delivering the material to project sites. Also, it will enhance the implementation of Just-in-Time delivery and material reuse/recycle process (Arbulu & Ballard, 2004).

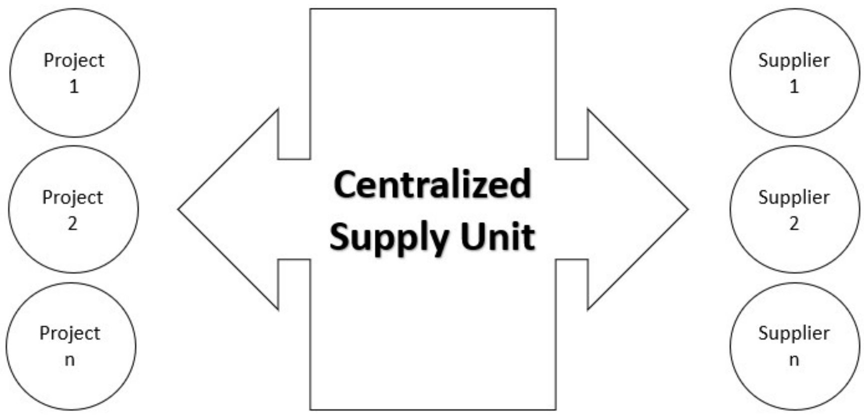

Figure 49 Construction centralized supply unit.

The centralized unit will receive all the projects' needs and analyze them, create a master material log that covers different projects' needs, contract all the suppliers required, provide them with the overall material requirements and delivery plans, supply different sites with their actual demand when needed, and finally handle any extra surplus material that might occur.

Also, the centralized unit will be the link between different project within a construction firm, where temporary material; scaffolding, formworks, etc., can be distributed among projects based on their needs as defined in the master schedules and the lookahead schedules; this will reduce the costs from purchasing, handling and storing additional temporary material.

5.5. Lean Site Management

This section will handle the application of lean principles and techniques during the execution phase to enhance the achievement of daily tasks on the construction site. Construction sites involve the use of manpower, machinery, and material to execute planned tasks for project development, organizing and coordinating among all of these is the goal of site management. This is achieved by setting plans, implying logistics, and supervision. Project complexity makes it challenging to handle all these inputs and coordinate between them, therefore, waste is generated through daily site activities; material waste, insufficient productivity, safety threat, and environmental hazards. The aim of lean techniques is to adjust the site environment to be suitable for construction execution. Kaizen and 5s are the main techniques that have an impact on daily site activities; site environment, logistics, and work execution. The cycle process for both techniques is presented in figure 50.

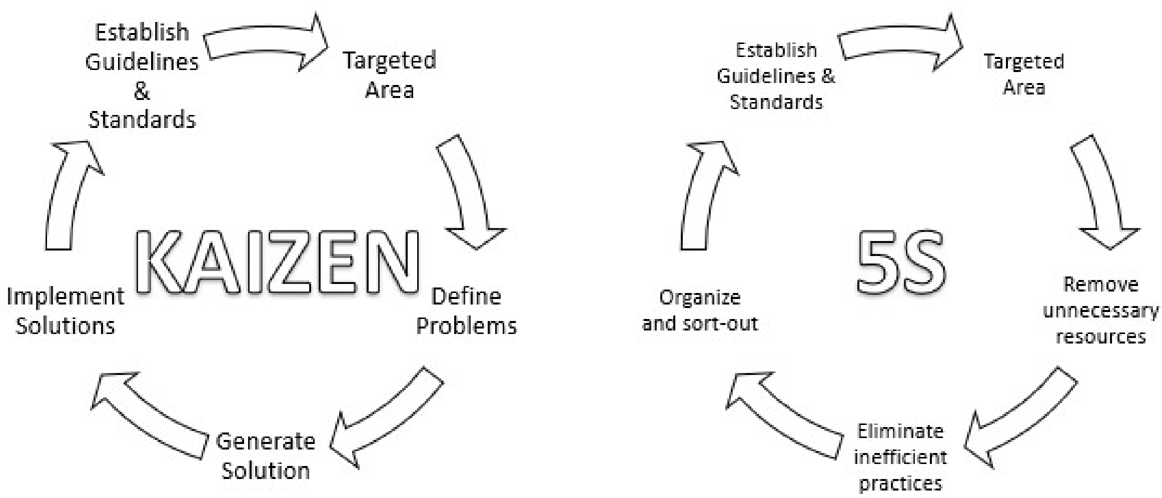

Figure 50 Kaizen & 5s technique to create a better construction culture.

The site environment is defined as all factors affecting the work environment within site boundaries; manpower allocation/interaction, material stocks, on-site storage areas, machinery, and HSE factors. As explained under lean construction/Six Sigma techniques in the previous section; kaizen and 5s are techniques to observe site issues, rectify and ensure non-reoccurrence through project lifecycle; learning workshops, setting up rules and regulations, and implementing continuous site issues tracking.

Site management can be improved by Integrating the process of both Kaizen and 5s in studying the practices on site for different projects, then use the results to prepare site management plans; method statements, safety management plans, quality management plans, environmental management plan, human resource management plan, and machinery management plan. These plans will be shared with project participants, workshops will take place to discuss and spread the knowledge among the project team and updated regularly to fit project execution processes.

The traditional focus shows that the workers' culture has a direct impact on their working behavior therefore, the impact on the site environment. Lean focus is to define the correct site practices and train the workers to adapt and share it therefore, improve workers behavior which will directly impact the construction culture (Pons, 2017).

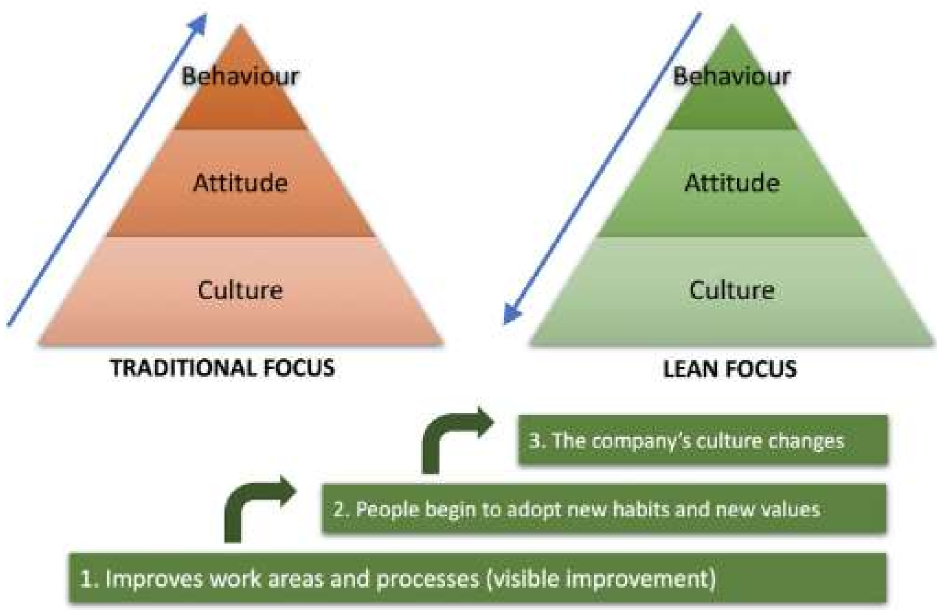

Figure 51 Lean focus on improving construction environment. Source: (Pons, 2017).

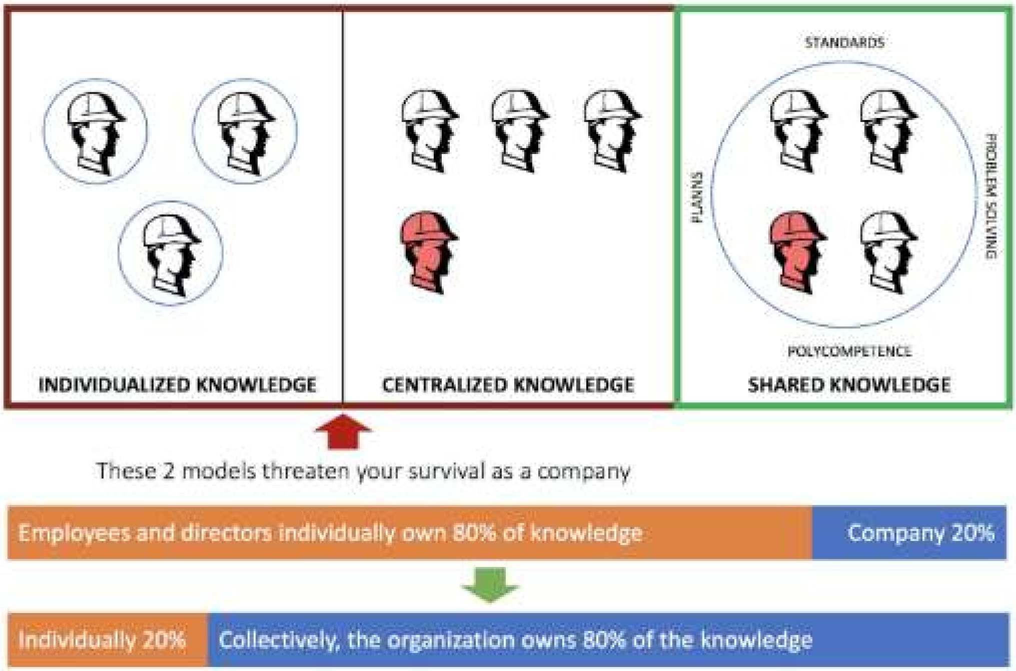

Figure 52 Lean focus on knowledge sharing. Source: (Pons, 2017).

The process of using kaizen and 5S techniques to improve site working environment can be integrated applying the process map presented in figure 53.

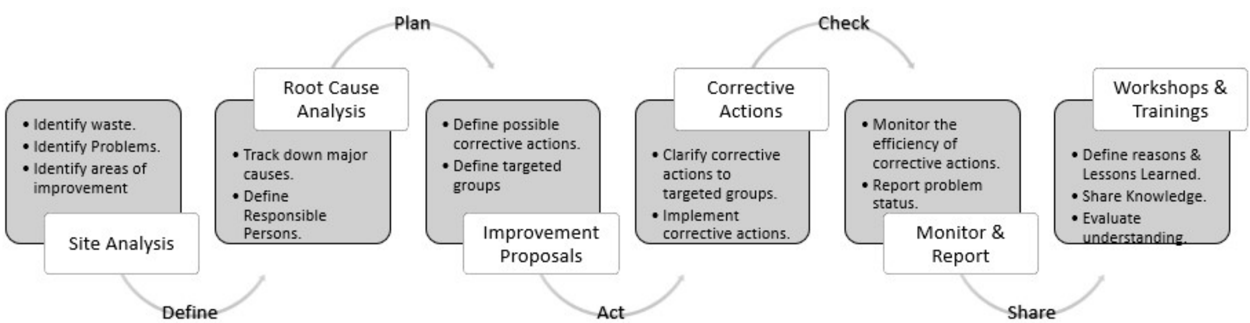

Figure 53 Integrating Kaizen & 5S to improve construction site work environment.

The process of developing an efficient construction culture within a construction firm is a continuous process and results can be noticed on the long run, therefore, the project management team should dedicate efforts and show patience to support the idea.

5.6. Lean Quality Management

Lean quality management is the idea of applying quality management system to support lean principles, Micklewright, founder of "Quality Quest Inc" established the future basis of this concept in his book "Lean ISO 9001" published in 2010 (Micklewright, 2010), the book addresses the practices of integrating Lean management into ISO 9001-based Quality Management System (QMS). From the vision that both QMS and lean principles are addressing the same concerns for project development, where both aim to enhance the processes through the project lifecycle.

The main idea here is to implement lean techniques to enhance the quality of processes carried out during the project lifecycle. Quality control is one major aspect through the project development, it includes the preparation of quality specifications, standards and plans. Moreover, method statements for construction works, and inspection requests must follow the lean principles, if we are aiming to integrate lean principles within construction project management then, it must cover all the aspects.

Although there is no official standards or guidelines to follow for the implementation of lean quality management, Micklewright used the techniques of Kaizen & 5s to reduce the resources needed in generating project quality documentation, this may be the main key for opening the door towards defining specific standards and guidelines for lean quality management (Bacoup, Michel, Habchi, & Pralus, 2017).

Instead of focusing on enhancing the quality control procedures using Kaizen and 5s, the author proposes two approaches to rectify the quality management style;

- **Quality control-DMAIC model**

Integrating Six Sigma DMAIC model’s methodology within the preparation of quality control plans and quality assurance plans.

Define; the major quality concerns during project execution and list them in project quality aspects log;

- Non-Conformance Reports
- Inspection Requests
- Requests for Information
- Material Approval Requests
- Material Inspection Request

- Safety Accident
- Safety Near Miss
- Fatality
- Complain Notices.

Measure; establish a KPI system that measures the fulfillment of these aspects;

- Approval rate
- Rejection rate
- Issuance rate
- Occurrence rate
- The number of reported accidents
- The number of reported complains.

Analyze; carry out analysis to determine the major factors related to each aspect listed in the log

Improve; propose procedures and practices based on the factors defined in the analyze step to improve the fulfillment of these aspects

Control; reflect the procedures and the practices in quality control plan and quality assurance plan documents and monitor the fulfillment of quality aspects during project development.

- **Activity Tagging System**

This approach is based on defining a tag system for project sub-activities as presented in figure 54, where all quality related information and even other valuable inputs are presented on sub activities level, for example, specification, standards, and regulations, this will help in;

- creating a clear quality vision for project participants
- Linking the scheduled activities with quality standards, specifications, and aspects
- Monitoring on-site quality aspects
- Improving the execution process

- Keeping a record of quality related issues on the activity level such as NCRs or Rejected IRs
- Simplify the handover process, where all documents can be directly generated from the Tag software.

The figure below represents the concept of the activity tagging system.

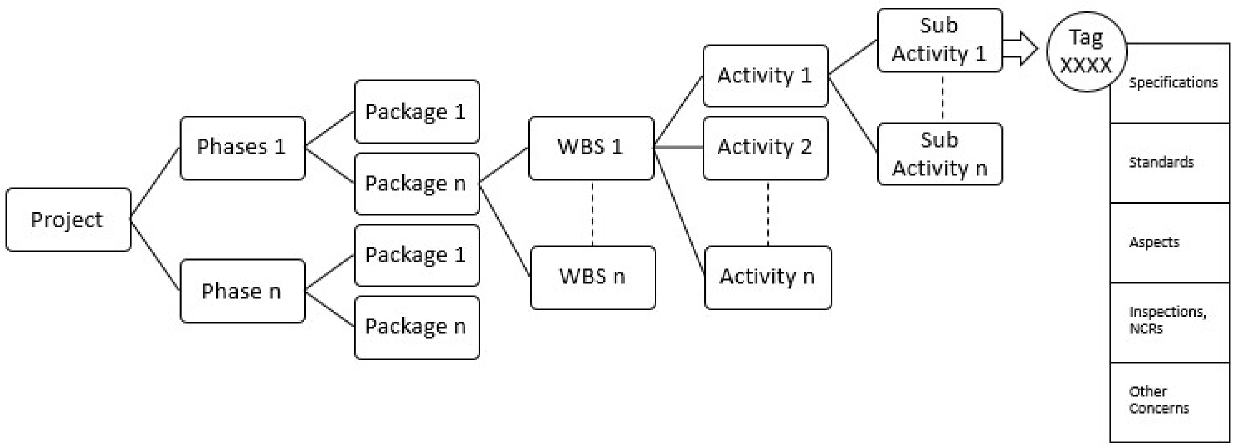

Figure 54 Activity tagging system.

5.7. Barriers in Integrating Lean Construction and Six Sigma with Project Management

Lean construction/Six Sigma are new concepts developed in the project management field therefore, many challenges and barriers influencing the implementation of this theory throughout project the lifecycle.

According to the study carried out by Sarhan and Fox in 2012 where they analyzed possible barriers affecting the implementation of lean construction in the UK, they found out that the main barriers and challenges are related to (Sarhan & Fox, 2012);

- The awareness and understanding of the lean construction principles; where the studies reflected issues in understanding the concept of lean principles, implementing the concept and realizing the true values gained from implying the concept.

- The commitment of top management to lean construction principles; as the results of implementing lean principles can be noticed on the long run and with the lack of management patience, lack of confident in the efficiency of this approach occurs.
- Conflicts and challenges related to variable cultural backgrounds; where different cultural attitude reacts differently towards the understanding and adaption of lean principles.
- Time and efforts involved in implementing lean construction principles; this process requires additional effort and time dedicated from all project participants, so with the same financial attraction for participants, it is hard to convince them to spend extra efforts for implying lean principles within a project.

Wandahl in 2014 summarized the challenges facing the implementation of lean construction in his research where he analyzed different research papers, he found that the main challenges are (Wandahl, 2014);

- Misunderstanding of the lean construction concept by project participants
- Improper implementation of lean construction techniques during the project lifecycle
- The implementation of lean construction techniques is limited to improve site practices.

As a summary based on the researches, the challenges and barriers affecting the implementation of lean construction can be summarized under the categories showing in figure 55.

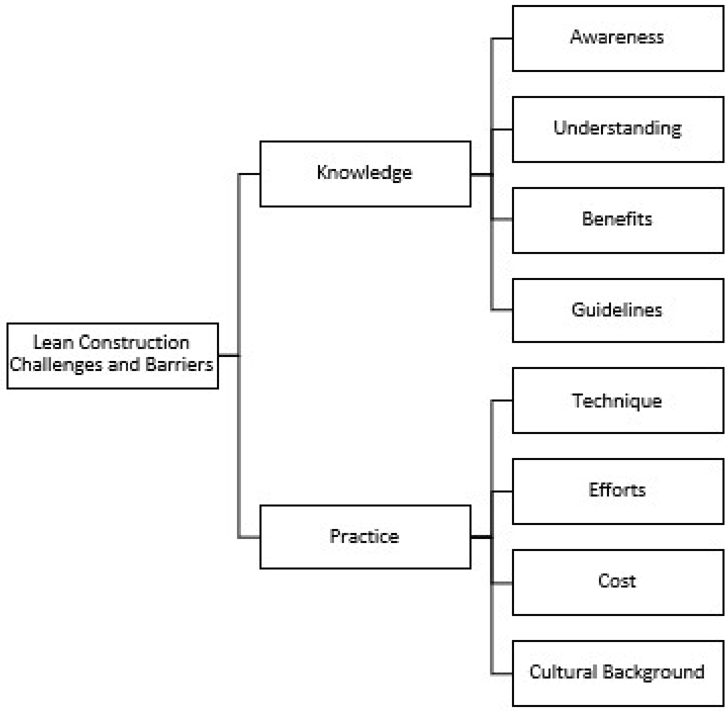

Figure 55 Lean construction barriers and challenges.

Now after highlighting the possible barriers and challenges affecting the integration of lean construction within project management, let us shed the light on proposals to reduce or even eliminate such barriers and challenges (Kawish, 2017);

- Carrying out workshops and training explains Lean Construction principles and techniques for project participants. These training should emphasis on root cause analysis and continuous improvement cycle through project development.
- Involving all parties on board in the decision-making process from the belief that everyone can add extra value to the project development.
- Setting up a rewards program for employees to encourage the idea of implementing lean principles through the project lifecycle.
- Establish a KPI system to measure the efficiency of lean construction implementation during the project lifecycle.
- Generating regulations to follow along with an implementation guidebook that aids the process of adopting Lean techniques.

6. Conclusion

The complexity of project's scale is the trigger of all challenges faced during project development, it has become challenging to fulfill client's requirement and needs using the traditional project management concept which mainly relies on addressing the terms of quality, budget and time. Tracking down the elements of the basic three terms of project management will simplify the management process and will positively balance them.

Project management and lean/Six Sigma management are two different concepts, where both involve the process of organizing performance of tasks using available resources within specific time and budget to achieve the project's goal, while lean management gives more attention to focus on the value of things as well as the occurrence of invaluable components, this is achieved through defining the value/waste during all project development phases. Implying the ideas of demand instead of supply, optimizing flow instead of maximizing flow, value generation and minimizing waste are the key concepts for driving project management process towards overcoming faced challenges.

Based on the literature review and the case studies analyzed using DMAIC model in this research, most of the challenges identified are related to six major fields relying on the root cause analysis;

- Knowledge and communication; information's availability, reliability, analysis, sharing, and utilization
- Design; mistakes, miscoordination, constructability, client's additional requirement and delivery
- Planning and scheduling; construction methodologies, resources allocation, cash flow distribution, delays, change in scope and design
- Construction site; logistics, actual productivity, practices, and physical waste
- Construction supply; material availability, material delivery, material handling, and surplus material
- Quality; change in standards, change in specifications, quality control, and assurance during execution.

Integrating lean principles within these fields is the vision to overcome and reduce the possibility of such challenges to occur during project development. The outcomes of this research have led us to define the following management fields;

- Lean knowledge and communication management; ensuring the value of project information is properly defined and delivered to the concerned parties in the right form and on-time.
- Lean design management; defining the project's objectives and transferring it into models, drawing and methodologies to achieve the maximum value possible and reduce the possibility of design changes during execution.
- Lean planning and scheduling management; ensuring continuous workflow with the use of optimum resources while maintaining a positive project cash flow. In addition to, proper monitoring and controlling of site tasks during execution and the possibility of revising schedules based on the circumstances.
- Lean site management; developing a construction culture on site supported by lean principles serves the goals of generating value and eliminating waste.
- Lean supply management; developing a centralized supply unit within the construction firm responsible for handling suppliers, orders, storage, distribution and reuse/recycle.
- Lean quality management; developing a tool that links defined standards, specification and other concerns to the sub-tasks executed on site for avoiding conflicts and mistakes as well as simplify handing over procedures. In addition to preparing a quality control plan and quality assurance plan based on the implementation of the DMAIC model.

Although lean construction/Six Sigma shows great potential, many challenges have been identified affecting the implementation of the concept;

- Awareness and understanding of the lean construction/Six Sigma principles
- The commitment of top management
- Variability cultural backgrounds of employees
- Time and efforts required for implementation
- Misunderstanding, limitation and Improper implementation of the concept.

Luckily, these challenges can be overcome by carrying out the following suggestions;

- Workshops and training
- Cooperated decision-making process
- Rewards program
- Lean management KPI systems
- Regulations to follow along with an implementation guidebook.

7. Future Approach

This study covered a view of project management challenges based on many types of research and case studies within the construction field, which supported the author in defining the theoretical basis of implementing lean/Six Sigma principles within project management. This theoretical approach must be reflected on the ground and evaluated using different evaluation methods while applying the concept in different types of projects and locations.

The author recommends that;

- The theory can be developed into practices with defined procedure and guidelines
- Construction firms can use the procedures and guideline to implement the theory in project development and monitor the outcomes
- The use of different evaluation methods to compare the practical results with the defined theoretical results and integrate findings in order to update the basic theory
- Studying the possible barriers that lean management implementation might face and generate practices to handle it.

Declaration of Authorship

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

1st July 2019

Date

Signature of the student

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