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**INSTITUTE OF SCIENCE AND TECHNOLOGY**

# LEAN AND BIM BASED WASTE MANAGEMENT

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**Supervisor: Prof. Dr. Sema ERGÖNÜL**

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**MİMAR SİNAN GÜZEL SANATLAR ÜNİVERSİTESİ**
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# YALIN VE BIM TABANLI İSRAF YÖNETİMİ

**YÜKSEK LİSANS TEZİ**

**Gökhan DEDE**

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Gökhan DEDE tarafından hazırlanan LEAN AND BIM BASED WASTE MANAGEMENT adlı bu tezin Yüksek Lisans tezi olarak uygun olduğunu onaylarım.

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Bu çalışma, jürimiz tarafından Yapı Mühendisliği Anabilim Dalında Yüksek Lisans tezi olarak kabul edilmiştir.

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| | |
|---|---|
| **AEC** | **:** Architecture, Engineering And Construction |
| **AIA** | **:**American Institute of Architects |
| **BIM** | **:** Building Information Modelling |
| **CIFE** | **:**Center for Integrated Facilities Engineering |
| **CNC** | **:**Computer Numerical Control |
| **CPM** | **:**Critical Path Method |
| **CRC** | **:**The Cooperative Research Centre |
| **DB** | **:**Design-Built contract |
| **DBB** | **:**Design – Bid – Build Contract Type |
| **ERP** | **:**Enterprise Resource Planning |
| **GUID** | **:**Global Unique Identifier |
| **ICE** | **:**Integrated Concurrent Engineering |
| **ICT** | **:**Information and Communication Technology |
| **IFC** | **:**Industry Foundation Class |
| **IGLC** | **:** International Group for Lean Construction |
| **IPD** | **:**Integrated Project Delivery |
| **KPI** | **:**Key Performance Indicator |
| **LCM** | **:**The Lean Construction Method |
| **LCI** | **:**The Lean Construction Institute |
| **LM** | **:**Lean Manufacturing |
| **LPDS** | **:**Lean Project Delivery System |
| **LPS** | **:**The Last Planner System |
| **NIBS** | **:**National Institute of Building Sciences |
| **NIST** | **:**National Institute of Standards and Technology |
| **OICA** | **:** The International Organization of Motor Vehicle Manufacturers |
| **POE** | **:** Post Occupation Evaluations |
| **P-O-P** | **:**Products, Organizations, and Processes |
| **PPC** | **:**The Percent Plan Completed |
| **RFI** | **:** Request For Information |
| **TFV** | **:**Transformation-Flow-Value |
| **TPS** | **:** Toyota Production System |
| **VDC** | **:**Visual Design and Construction |
| **WBS** | **:**Work Breakdown Structure |
| **2D** | **:**Two dimensions: x and y |
| **3D** | **:**Three dimensions: x, y and z |
| **4D** | **:**A 3D model integrated with a time plan |
| **5D** | **:**A 3D model integrated with cost estimation |
| **6D** | **:**A 3D model integrated with project lifecycle information |
| **7D** | **:**A 3D model integrated with the operation and maintenance |

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## LEAN AND BIM BASED WASTE MANAGEMENT


### ABSTRACT

In recent years, increasing competitiveness in construction sector leads stakeholders to focus on customer-oriented and competitive-based projecting, construction and operation. Lean Production Principles and Building Information Modelling (BIM) are two different methods that are used for developing different phases of projects in order to achieve customer expectations.

Lean Philosophy is a kind of value engineering tool that eliminates all product wastes to maximize customer expectations. These systematic thinking approach emerge in Auto Industry and become an inspiration source for other sectors including Construction Industry. After successfully implementation in manufacturing industry, lean concepts have become a domination issue in construction fields for many years. All stakeholders have aimed reducing waste and increasing productivity to provide client's requirements of construction. According to Lean Philosophy, every unnecessary and irrelevant activities in project is a kind of waste and all these over operations should be eliminated from the production flow process.

Building Information Modelling is an innovative tool as a three dimentional modeling tool in construction industry but recent years, cost, time, sustainability and facility arguments have been integrated with this tool for providing well-coordinated project model that could be used for design, feasibility, scheduling, bidding, building analyzing, construction and facility management phases. BIM concept aims improving workflow visulation of project step by step and stakeholders could be able to specify project's clash detections, mistakes and wastes before the execution phase. Therefore, BIM and Lean Construction Methods aim at the same goal in terms of being well-coordinated and well-collaborated projects which result in customer satisfaction.

This study aims to analyze the integration of Lean Construction Methods with BIM by identifying and classifying wastes in construction industry in relation to Lean Production Waste Types. Interviewshave been conducted with 5 construction firms in order to clarify the construction waste types and their frequency of occurrence inTurkish Construction Industry. The data obtained are analyzed and interpreted to develop solutions to reduce wastes in Turkish Construction Industry by suggesting the use of Lean Construction methods and BIM.

# YALIN VE BIM TABANLI İSRAF YÖNETİMİ


## ÖZET

Son yıllarda, inşaat sektöründeki artan rekabetçilik, paydaşların müşteri odaklı rekabete dayanan projelendirme, inşaat ve işletme süreçlerine yönelmelerine sebep olmaktadır. İnşaat endüstrisine yön veren bu durum, müşteri beklentilerini maksimize edecek farklı yöneyim araçlarının kullanılmasına yönelik çalışmalara hız kazandırmıştır. Yalın Üretim Prensipleri ve Yapı Bilgi Modellemesi (BIM) bu araçlardan ikisidir.

Yalın Felsefe, gerekli olan tüm istafları ortadan kaldıran bir çeşit değer mühendisliği metodudur. Bu sistematik düşünme yaklaşımı Otomotiv Endüstrisinde ortaya çıkmış olmasına rağmen İnşaat Sektörü de dahil olmak üzere diğer endüstriler için de ilham kaynağı olmuştur. İmalat sanayinde başarılı olan uygulamalardan sonra, Yalın Üretim Prensipleri inşaat alanlarında dahakim bir konu haline gelmiştir. Hem müşteri beklentisini karşılamak hem de üretim verimliliğinin arttırmak için proje , inşaat ve işletme sürecindeki atıkların bertaraf edilmesi ya da minimum seviyede tutulması hedeflenmiştir. Yalın Prensibikapsamında, müşteri iştekleri ve beklentileri haricinde oluşan, ayrıca zaman ve maddi kayba olanak tanıyan her etkinlik bir tür atıktır ve üretim süreci sonunda ortaya çıkan ürün sadece müşterinin son ürün tanımına ve beklentisine cevap verdiği ölçüde başarılıdır.

Yapı Bilgi Modellemesi (BIM), inşaat endüstrisinin tasarım, projelendirme, fizibilite, planlama, ihale dokümanları üretimi, bina enerji analizleri, inşaat ve tesis yönetimi gibi aşamalarındakullanılabilecek yenilikçi yazılımlar bütünüdür. BIM, bütün üretim aşamalarının hepsini aşama aşama açığa çıkaran, hepsine müdahale edebilmeyi sağlayarak diğer paydaşlar ile koordineli akışı mümkün kılan ve proje süreçlerindeki tüm hataların fark edilerek düzeltilmesine imkan veren bir yöntem olarak son yıllarda inşaar sektöründe önemini arttırmıştır.

Bu çalışmanın ilk aşamasında, başlıca üretim teorileri ve bu teorilerin israf türleri ile değer üretimi tanımlarına yer verilmiştir. Ayrıca, benzer tarihi ve kültürel özelliklere sahip gelişmekte olan 3 ülke için yapılan Yalın İnşaat Methodları konulu çalışmalar incelenip açıklanmıştır.

İkinci aşamada, Yalın Üretim Prensiplerinin ortaya çıkış sürecine, prensiplerin açıklamalarına ve inşaat sektöründeki yansıması olan Yalın İnşaat konseptine yer verilmiştir.

Üçüncü aşamada,Türkiye İnşaat Endüstrisindeki meydana gelen kayıpların sebeplerinin tespit edilebilmesi için sektördeki 2 mimari ofis ve 3 inşaat yapım şirketi olmak üzere 5 firmanın proje sorumluları ile yüzyüze yapılan görüşmelere yer verilmiştir. Yalın üretim prensiplerinde Taiichi Ohno tarafından belirlenen başlıca 7 israf kaynağı dikkate alınarak yapılan görüşmelerde Türk İnşaat Sektöründe karşılaşılan israflar analiz edilmiştir.

Çalışmanın dördüncü aşamasında, Türk inşaat sektöründe tespit edilen kayıpların azaltılması ve giderilmesi için başvurulması gereken Yalın İnşaat Metodları ve Yapı Bilgi Modellemesi kavramlarının arasındaki kavramsal etkileşimler, ortaya çıkabilecek pozitif fonksiyonlar ele alınmıştır ve geliştirilen proje yönetim sisteminin gerekliliği açıklanmıştır.

Bu çalışma, Türk inşaat sektöründeki firmalar ile yapılan görüşmeler sonucunda belirlenen ve Yalın Üretim Prensiplerine göre sınıflandırılan israfları minimum seviyeye düşürmeyi sağlayacak Yalın Yapım Yöntemlerinin gerekliliğini ve BIM ile entegrasyonunu analiz etmeyi amaçlamaktadır. Yalın İnşaat Metodları ve BIM entegrasyonu sayesinde, Türk İnşaat Sektöründeki atıkların azaltılması için kullanılacakproje yönetim modeli önerilmiştir.

# 1. INTRODUCTION

## 1.1 Background

The construction industry possesses several hurdles such as tight schedule, inadequate skilled manpower, inadequate budget, and other leftover main capacities, which seem to be the basis for unsuccessful execution of the project.

Over the past years, several development have been introduced to improve the efficiency of project phases by decreasing wastage in AEC. The one major concept spread rapidly in AEC is Lean Construction Principles that are based on Japanese automobile industry company's lean manufacturing principles and that company is Toyota (Womack, et al., 1990). The another major development is the use of computer based design tools that evolved the information technology in the form of CAD systems to design projects and this technology is known as Building Informatiom Modelling (BIM) (Eastman, et al., 2011).

Womack et al. (2007) define the basic idea of lean production that is eliminating all kinds of waste for realizing client's expectations with a better way. Koskela (1992) pointed out waste as "any inefficiency that results in the use of equipment, materials, manpower or capital in larger quantities than those considered as necessary in the production of a building". Taiichi Ohno (1988) who was a Japanese industrial engineer and founder of Toyota Production System identifies 7 basic type of waste in production. Seven basic types of waste are classified as follows:

1. defects that must be corrected (Correction Waste) ,
2. overproduction (producing more or doing more than is needed),
3. inventory,
4. unnecessary processing steps, (Over processing Waste)
5. transportation of materials with no purpose,
6. motion of employees with no purpose,

7. waiting by employees for process equipment to finish its work or for an upstream activity to complete, (Waiting Waste).

After first applications of Lean Principles in construction industry, Last Planner System was develop to test lean approaches and to prove waste reducing of implementations.

Construction movement to Lean Principles started in 1993 and professionals established a research group that International Group for Lean Construction (IGLC) that gave a start for practicing, educating, and researching on lean construction to solve the wastages in construction industries. IGLC played a pozitive role for the renewal of constrcution phases (International Group for Lean Construction, 2008).

In 1997, The Lean Construction Institute (LCI) was founded in the USA to achieve knowledge project management in the design, engineering, and construction of capital facilities by maximizing the value engineering while the waste is reduced.
Until 2000, conventional lean construction method seperated designers and constructors as an individual actor. This seperation caused disagreements between key stakeholders of the project. Incompetent designing and documentation, time and cost overruns and frequent recurrences of rework (poor quality) occurred in the project. Ballard (2000) formulated the Lean Project Delivery System to prevent conflicts between project actors and fix wastages as much as possible for maximizing value of project components.

Although the AEC industry suggests several techniques for minimizing the waste, ensuring on schedule delivery of the project and limiting the price range. The construction industry is viewing success up to a certain extent through the BIM and the Lean Construction techniques, even though generally the industry is challenged by various problems. Implementing Lean tools in the industry is the suggestion given by few researchers such as Koskela and Sacks(Sacks et al. 2010).

The emergence of BIM concept became in the 1970s as a solution for incompetences and conflicts in the AEC industry. The coherence in the other industries was role model the advent of BIM concept. Graphisoft's ArchiCAD was the pioneer software that is the first recorded practical implementation of the BIM in 1987. This software begun an innovative of trend that was followed by other

software companies like Autodesk, Bentley systems etc. In 1992, Van Nederveen was the first author to term the virtual building concept as Building Information Modeling (BIM) and the term has been embraced by the AEC Industry ever since. In the mid-2000s, the peakin the implementation of this technique was at its peak (Azhar, et al., 2012).

BIM contains 3D intelligent and parametric construction objects that could be modified according to the client's requirement to avoid wastes, BIM represent an enclusive model which is not only used for design project, but also used for construction and facility management.As the detail level of the model increase, the coherence of project actors is getting more to provide a clear understanding of the project.

The BIM is a project system software which also serves the purpose of data management software that plans and organizes the final product to achieve a complete hierarchy to form the project through connecting small conceivable and manageable chunks. It can be said that the BIM has open doors to production and management of a parametric version of constructing. However, the AEC is not as technologically advanced as other comparative industries.

Implementing of Lean Principles serve for the same purpose with BIM that finds best solution to fit well what is required by client. These principles which are formulated by Toyota that created the Toyota Production System (TPS), aim to decrease wastages, reach clients' expected value and guide to permanent and sustainabledevelopment in the assignments in projects (Sacks, et al, 2010).

As Sacks (2010) says that, there are ten substantial synergies between the Lean Construction and Building Information Modelling (BIM) from the design phase to the execution and facility management phases of the project.Sacks (2010) suggests three main interaction between lean concept and BIM in design phase of project provides Lean Construction Principles. The first of these is that different project team actors can edit and modify to different design alternatives to create satisfaied project model which shows the functionality of BIM in the rapid generation of design alternatives and from lean principles it shows how the design of the production system and flow of value is made (Eastman, et al., 2008).

The second interaction of the Sacks (2010) study is about collaboration and communication between project stakeholders to work in parallel with the same model which means that the workload is shared according to the expertise of different teams. Thus, it is possible to have a high quality since each piece, for example, while structural and architectural designs can be carried out with reference to one another, they ensure that the two plans fit together and therefore do not just design aesthetics.

The third interaction is that BIM provides visualization of the project and the projection flow, the construction of the construction site, and simulation to identify the potential resource conflicts and clashes in the day to day production. With Lean Construction having an objective to create flow of the tasks, this is complimented by that while using BIM, resources can be allocated in a way that is planned for a flow to keep going without resources being over or under used (Sacks, 2010).

### 1.2 Aim of The Study

The aim of this studyis to lead to the research question; what effectiveness of waste causes are in Turkish construction industry and how a Lean Principles and Building Information Modelling (BIM) based project management approach can be used to increase efficiency of project processes from desing phase to facility phase of a Project.

### 1.3 Research Methodology

The research methods to achieve the main aim of the research are as follows:

1. Literature search on Construction Waste Management.
2. Literature search on Lean Production Principles
3. Interview with construction firms in order to define main waste causes in Turkish Construction Industry.
4. Integration of Lean Principles and BIM to see how they can be used to increase efficiency in construction waste.
5. Proposal of a Lean & BIM based waste management approach for construction industry.

# 2. WASTE MANAGEMENT METHODS IN CONSTRUCTION

## 2.1 Value And Waste Definitions In Construction Industry

The construction industry is becoming technologically advanced but it is still based on human power, facing lots of restrictions such as weather, design changes, procurement, construction methods etc., furthermore the uncertainty regarding the uniqueness of the Project. Risks are developed with uncertainty, thus affecting the application of the Project, thus building a chain reaction which may further reduce the efficiency of construction by converting into wastes, which are categorized into related process, technology and policy limitations. Figure 2.1 shows waste time in construction industry. According to Construction Industry Institute (2004), occurancy of wastes related with process limitations and optimal use of resources have been affected due to the method followed or order of work.

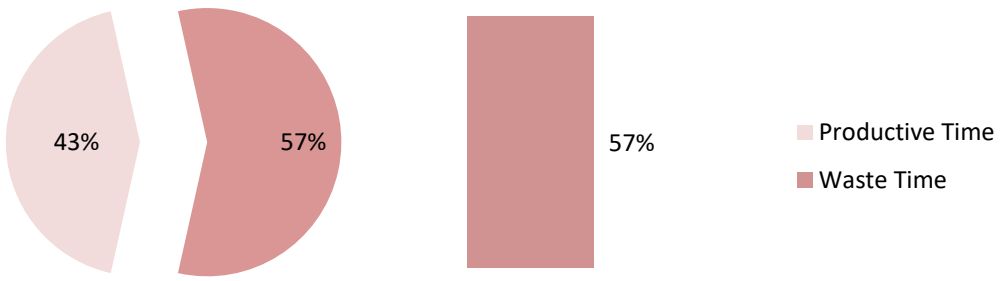



**Figure 2.1 :** Waste Time In Construction Industry (Constrcution Industry Institute, 2004).

The used input and gained output are balanced by the flow order of work activities and the flow is stopped or continued to manage and control the process. Production flow can be sustainable under commercial conditions in a capitalist system that means produced value and waste in work flow equal price and unneeded costs. Value is a desired output but waste refers to used resources more than needed.

Value means profitable, functional and helpful gains to answer project needs. According to Koskela (2000), value is the fulfillment of customer expectations. On the other hand, Womack and Jones (2003) describe waste that has no value for project profits. In 2000, Koskela argues that ” A product with a wonderful value may

be produced in a most wasteful process. On the other hand, a product with a clearly deficient value may be produced in a most waste-free process."

## 2.2 Waste Perspectives For Theories Of Production

In construction and production industry, there are four main Production Theories that has become effective for these industries for years. Main production theories are;

1. Transformation Production Theory,
2. Flow Production Theory,
3. Value Production Theory,
4. Lean Production Theory.

Each production theory has different waste definitions that are explained below.

### 2.2.1 Waste equals material loss in Transformation Production Theory

Koskela (2000) states that the transformation process is a linear process and it is deducible with an analysis of production in larger units, whereas operation process can be deducible with the analysis of production in small units. Therefore, the processes and operations are considered a linear operation lying on the same axis; improvements in the total process will be achieved when the small unit operation improves. Transformation is the use of resources to alter the state of something input to produce the outputs needed. The production process is referred to this transformation from one set of resources to a second set (Koskela, 2000). The transformation process can be disintegrated into subprocesses that are also transformation processes; the cost of the total process can be reduced by decreasing the cost of each sub-process. Building systems for industrialized construction can be explained as the collected understanding and information on how to comprehend a construction project;therefore it can be standardized as

**Input → Production → Output.**

In the Transformation Production Theory, raw material transformation means productions and use of machinery, energy and labor are products, so that waste is defined as used production resources more than needed in production flow. In transformation production theory, there are three types of waste; material waste, non-optimal use of material and non-optimal use of machinery, energy or labor.

Consumed material is not included in the final product determines material waste in production. Optimal use of resources bases on current level of knowledge and technology in industry, necessary use of products will be considered as waste at a later point.

### 2.2.2 Waste equals time loss in Flow Production Theory

Koskela (2000) explains that flow plays a role in eliminating the waste from flow processes by reducing lead time and minimizing variability, Koskela (2000) refers to waste types of Taiichi Ohno (1988) who identified the following seven wastes regarding material flow as listed below:

1. **Waiting waste or delay:** The time during which the system remained inactive is waiting waste, which happens if a preceding task wasn't delivered on time or completed entirely. The cycle time is increased by waiting as no value added activity is performed.
2. **Motion waste:** No value is added to the product or service and time is consumed when steps are taken in excess by people to accommodate a process layout that didn't perform efficiently due to defects, reprocessing, overproduction or excess inventory.
3. **Over processing waste:** During operations, the unnecessary steps performed that added no value to the product or service. When coming across defects, overproduction or excess inventory, over-processing might arise.
4. **Over production waste:** Excess production, before time manufacturing and if the task is completed prior to its need can be the root cause to this. As a result, the product is in excess, production has been done early and costs of carrying excess inventory are found.
5. **Transformation waste:** This is the movement of products or materials that is not required, that aren't involved in immediate production. The movement during which no value-added activity is being performed and the material can easily be damaged should be minimized .

6. **Inventory waste:** This refers to excess materials being supplied, other than what is needed to build the current phase of the project. The money will be tied up this way and the inventory will keep on increasing which may require extra handling and space.
7. **Correction waste:** This refers to Products, materials or services that are not what is required or are not in accordance to specification. Corrections and defects refers to work done incorrectly initially that needs to be fixed, sorted, remade or re-done, or scrapped due to defects.

### 2.2.3 Waste equals value loss in Value Production Theory

The focus of the value generation concept is dependent on the relation between customer demands and the supplier value production. The benefit that a customer acquires from a product or service in comparison with its cost is the customer value. A customer's perception of value is dependent on quality of the product, service quality, price, and image. In a supplier–customer relationship, the dimensions of the supplier's value creation could be classified according to efficiency, effectiveness and network functions. These are interconnected functions, but conceptually they are different.

The process of value creation could be explained as a spectrum ranging from core value, to added value, to future value (Moller and Pekka, 2003). The output that fulfils the requirements, wishes and needs of the customer is more important than the transformation of the product itself. Koskela et al. (2010) identfy 4 main reason of value loss;

1. Lack of quality (incl. defective product)
2. Lack of intended use Related to by-products
3. Harmful emissions
4. Injuries and work related sickness.

Table 2.1 represents waste classification of Transformation, Flow and Value Production Theories.

**Table 2.1:** Taxonomy of the wastes of production in construction (Koskela, et al. 2014)

| | **Transformation** | **Flow** | **Value** |
|---|---|---|---|
| **Production Resource** | Materials, machinery, energy and labour | Time | Value |
| **Type of Waste** | Material loss | Time loss | Value loss |
| **Waste** | 1. Material waste<br>2. Non-optimal use of material<br>3. Non-optimal use of machinery, energy or labour | In the work flow<br>1. Unnecessary movement (of people)<br>2. Unnecessary work<br>3. Inefficient work<br>4. Waiting<br>In the product flow<br>5. Space not being worked in<br>6. Materials not being processed<br>7. Unnecessary transportation (of material) | Main product<br>1. Lack of quality<br>2. Lack of intended use By-product<br>3. Harmful emissions 4. Injuries and work related sickness |

### 2.2.4 Waste equals material, time and value loss in Lean Production Theory

Taiichi Ohno (1988) is defined waste as any activity that does not add value to the customer expected product or that the customer is not willing to pay for. According to Ohno, waste occurs in every process and in organisation and no matter how effective or efficient a process may be, some level of waste is always present. The waste issue was the main hindrance in the way of worker productivity. The larger production led to faults in the cars which were handed over to receivers by the American engineers, whereas, Toyota worked on achieving non-waste (Baines et al., 2006). Other aspect is that failures occur as the consequences of halting a production line. The test proved to be beneficial for the company. For instance, decentralization of decision making was found beneficial. Other point proved was that labored people had a better understanding of the targets of production and decisions made by them are also imperative to stimulate the production. Additionally, this would give empowerment to the workers (Baines et al., 2006). Figure 2.2 shows Ohno's waste

definition as an diagram by seperating activities as value-adding or non-value adding activities.

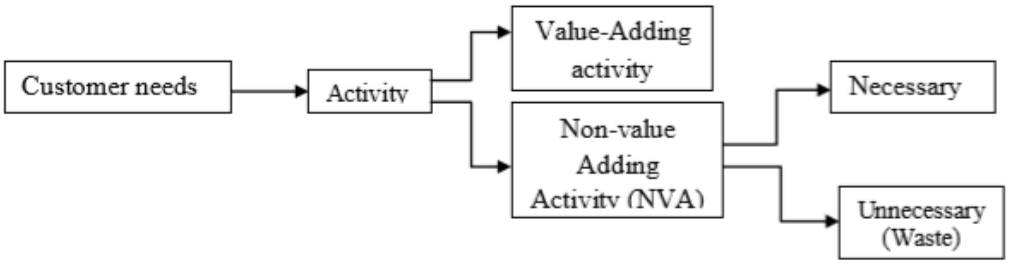



**Figure 2.2 :** Value Adding Activities (VAA) and Non-Value Adding Activities (NVA) (Alazmi et al., 2013)

Ohno (1988) categorized wastes in seven forms that exist in production process that should be continual and perfect for lean production (Ohno, 1988). Table 2.2 explains seven waste categories and their meanings in lean production.

**Table 2.2:** Taiichi Ohno' s waste classification and definitions (Ohno, 1988)

| **Waste Categories** | **Definition** |
|---|---|
| Transportation | Moving products that do not need to be moved |
| Inventory | Work and finished work not being processed |
| Motion | Equipment or people moving more than necessary |
| Waiting | Time lost in between steps in production |
| Over-Processing | Poor use of tools and in the production of the goods that the customers do not need |
| Overproduction | Production moves ahead of demand |
| Defects | Extra effort involved in fixing problems |

## 2.3 Construction Waste Analysis of Developing Countries

United Arab Emirates, Saudi Arabia and Turkey are the developing countries that have growing economies with construction based strategies and their historical backround, similar culture and demographic structure present comperative conditions to analyse each construction wastes.

### 2.3.1 Construction waste analysis of Abu Dhabi ( United Arab Emirates)

Research analysis of Raid (2012) exposed 27 waste causes in Abu Dhabi construction industry. As shown in Figure 2.3, late work delivery and long approval have the highest occurrence frequency in construction wastes. Raid states that the top 10 wastes range from work interruptions to late work delivery and represent 46.5% of construction wastes.

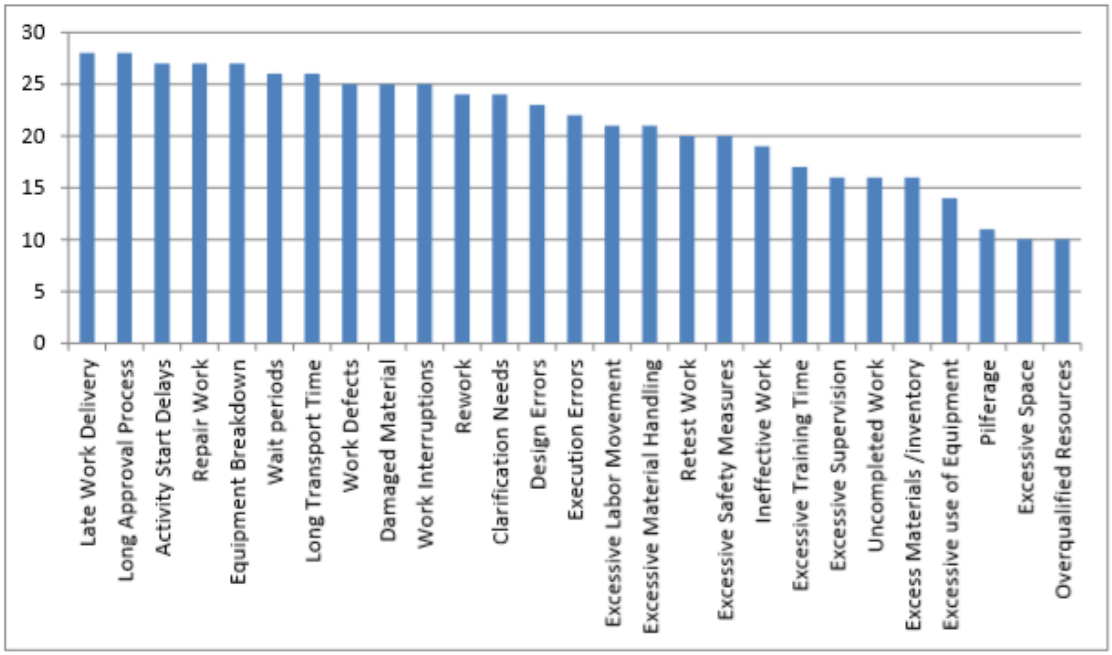



**Figure 2.3 :** Analysis Of Waste Causes at Abu Dhabi Construction Industry (Raid, 2012)

In research, identified 27 waste causes were categorized into the typical 7 waste categories of lean production (defects/errors/correction, delay, over-production, over-processing, excessive inventory, excessive conveyance, and excessive motions). Figure 2.4 shows the categories of identified construction wastes.

| Correction | Over-processing | Delay | Inventory | Conveyance | Over-production | Motion |
|---|---|---|---|---|---|---|
| Repair Work | Long Approval Process | Late Work Delivery | Damaged Material | Transport Time | Idle periods | Labor Moves |
| Equipment Breakdown | Clarification Needs | Activity Start Delays | Excess Materials | Material Handling | Excessive Space | |
| Work Defects | Excessive Safety | Work Interruptions | Pilferage | | | |
| Rework/ Re-run | Excessive Training Time | Ineffective Work | | | | |
| Design Errors | Excessive Supervision | | | | | |
| Execution Errors | Excessive use of Equipment | | | | | |
| Retest Work | Overqualified Resources | | | | | |
| Uncompleted Work | | | | | | |

**Figure 2.4 :** Types of Construction Waste in Abu Dhabi Construction Industry (Raid, 2012)

After categorization of waste types, occurrence frequency of each 7 waste types represented as shown in Figure 2.5. As seen from Figure 2.5, correction of errors and defects is on the top of waste categories followed by over-processing and delay. The three represent 72.5% of all construction wastes. This percentage represents the cumulative relative frequencies of the first 3 waste categories. This clarifies the status of current wastes in AD construction industry and provides guidance of the improvement process.

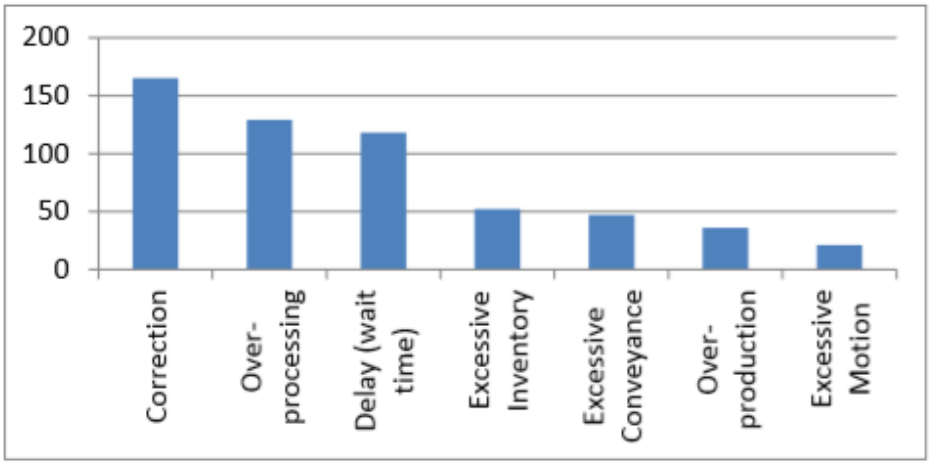



**Figure 2.5 :** Analysis of Waste Types at Abu Dhabi Construction Industry (Raid, 2012)

### 2.3.2 Construction waste analysis of Saudi Arabia

In the Saudi Arabia, as shown in Figure 2.6, “Waiting” waste has the highest mean value of 3.58 and is ranked first (Sarhan et al., 2017). The second ranked waste type is “Making do” with a mean value of 3.43. The lowest mean value score is for “over production”with an overall mean of 2.96.

| Types of Waste | Overall Mean | S.D. | Rank | Small and Medium companies | Rank | Large companies | Rank | ANOVA *p*-value |
|---|---|---|---|---|---|---|---|---|
| Waiting | 3.58 | 1.14 | 1 | 3.49 | 1 | 3.56 | 1 | 0.076 |
| Making do | 3.43 | 1.94 | 2 | 3.44 | 2 | 3.45 | 2 | 0.670 |
| Corrections | 3.38 | 1.13 | 3 | 3.30 | 4 | 3.37 | 3 | 0.096 |
| Transportation | 3.38 | 1.09 | 4 | 3.42 | 3 | 3.34 | 5 | 0.852 |
| Motion | 3.28 | 1.16 | 5 | 3.23 | 5 | 3.35 | 4 | 0.661 |
| Over-processing | 3.25 | 1.14 | 6 | 3.14 | 6 | 3.21 | 6 | 0.002* |
| Inventory | 3.04 | 1.15 | 7 | 3.23 | 5 | 2.88 | 7 | 0.046 |
| Over Production | 2.96 | 1.17 | 8 | 3.14 | 6 | 2.76 | 8 | 0.027* |

**Note:** 1= Strongly Disagree to 5= Strongly Agree

**Figure 2.6 :** Analysis of Waste Types at Saudi Arabia Construction Industry (Sarhan et al., 2017)

According to research of Sarhan et al. (2017) research, the P-values of “Over processing” and “Over production” (calculated probability) are 0.002 and 0.027. Smaller companies has much more risk than large companies because of their limited resources.

### 2.3.3 Construction waste analysis of Turkey

In many construction industries around the world, wastes are the most critical project delivery problems that cause exceeding budget and schedule delay with the waste of resources.

Polat and Ballard (2004) analyzed waste in Turkish Construction Industry to prove necessity of lean construction tecniques and they got reference waste causes

classification of Bossink and Brouwers (1996) to define wastage in construction industry. Bossink and Brouwers (1996) sorted the main waste causes in 6 sources as; 1) Design 2) Procurement 3) Materials Handling 4) Operation 5) Residual 6) Other.

Polat and Ballard (2004) designed a survey for data collection to identfy the material and time waste causes in Turkish Constrcution Industry by asking closed questions for predictable answers and open-ended questions in order not to limit or guide the thinking of the repondents. Table 2.3 shows the distribution of material waste causes according to answer frequency of the practitioners and Table 2.4 presents respondents' answers to identfy main time waste causes .

**Table 2.3:** Main Causes of Material Waste, Polat and Ballard(2004).

| Source | Cause of Material Waste | Frequency(%) |
|---|---|---|
| Design | Lack of information about types and sizes of materials on design documents | 13 |
| | Design changes and revisions | 12 |
| | Error in information about types and sizes of materials on design documents | 10 |
| | Determination of types and dimensions of materials without considering waste | 3 |
| Procurement | Ordering of materials that do not fulfill project requirements defined on design documents | 86 |
| | Overordering or underordering due to mistakes in quantity surveys | 8 |
| | Overordering or underordering due to lack of coordination between warehouse and construction crew | 4 |
| Material Handling | Damage of materials due to deficient stockpiling and handling of materials | 16 |
| Operation | Imperfect planning of construction | 61 |
| | Workers' mistakes | 32 |
| | Damage caused by subsequent trades | 3 |
| Residual | Conversion waste from cutting uneconomical shapes | 22 |
| Other | Lack of on site materials control | 23 |
| | Lack of waste management plans | 10 |

**Table 2.4:** Main Causes of Delay, Polat and Ballard(2004).

| Source | Cause of Time Waste | Frequenc(%) |
|---|---|---|
| Design | Interaction between various specialists | 19 |
| | Rework due to design changes and revisions | 13 |
| | Lack of information about types and sizes of materials on design documents | 10 |
| | Error in information about types and sizes of materials on design document | 6 |
| | Contradictions in design documents | 3 |
| | Delay in approval of drawings | 3 |
| Procurement | Delay in material supply | 72 |
| | Receiving materials that do not fulfill project | 53 |

| | | |
|---|---|---|
| | requirements defined on design documents, and waiting for replacement | |
| | Delay m transportation and/or installation of equipment | 6 |
| Operation | Scarcity of crews | 29 |
| | Unrealistic master schedule | 23 |
| | Rework due to workers' mistakes | 16 |
| | Scarcity of equipment | 13 |
| | Waiting for design documents and drawings | 9 |
| | Lack of coordination among crews | 8 |
| | Choice of wrong construction method | 5 |
| | Accidents due to lack of safety | 4 |
| Other | Irregular cash flow | 39 |
| | Severe weather conditions | 35 |
| | Bureaucracy and red tape | 6 |
| | Unpredictable local conditions | 6 |
| | Acts of God | 5 |

Polat and Ballard (2004) findings display main material and time waste roots in Turkey. This reseach results in proving the obligation to use Lean Principles but, construction industry turns into software based project coordination and collaboration on a worldwide scale.

Waste management is the key factor of the project management for implementation of lean principles. The kind of waste that should be identified to apply Lean Project Delivery System (LPDS) that helps creating good communication skills and cooperation between stakeholders for succussful completion of construction with minimal wastage and maximized value.Production or prevention of new wastes depends on determination of main waste causes for every unique construction industry.

# 3. LEAN PRINCIPLES AND THEORIES IN CONSTRUCTION

## 3.1 What Is Lean Philosophy?

Before Engineer Taiichi Ohno from Toyota Company invented the new concept of lean philosophy, a different system was followed. The Ford and General Motors were two American companies that were considered as the leaders by employing the most advance car manufacturing system. Many American industries followed the mechanization plan of Henry Ford. While on a site visit, Ohno and Japanese engineers realized that the companies were just accustomed to the system by Ford Company. According to Ohno, "the waste of over production" was carried out by the American engineers. The vital point of production for the company should be efficiency. Due to unhandled pressure in the production line, defects were likely to arise. Additional pressure is then given to each unit of production thus resulting in over production. On the contrary, Ohno in each part, concentrated mainly on the waste (Baines et al., 2006). Ohno was of the opinion that by focusing on the whole production line, higher productivity can be achieved and the production would be more efficient (Baines et al., 2006). Subsequently, the Japanese engineers decided to employ the technique of production followed by Ford Company. The basic purpose was to have an onsite experience to be transferred. Toyota considered the worker productivity to be the basic subject.

Toyota concluded that minimum waste should be in the production line. Likewise, the process was also inspected by Ohno to gather maximum advantages. Taichi Ohno identified seven forms of waste that exist in a process:

1. Waiting Time – time spent waiting between activities,
2. Transport – movement between activities,
3. Component design – effectiveness of the tool in meeting its intended purpose,
4. Inventory – number of items of work at each activity step,

5. Over Production – any effort or output that exceeds the customer expectation,
6. Motion – movement within each activity,
7. Defective goods – outputs that do not meet the customer expectation.

The continuous identification and removal of waste are at the centre of continual development and operational perfection (Ohno, 1988).

Primary advantage here was that the time period to conclude the design process has been minimized. This was the result of the research and minimizing the time loss due to competition in the industry.

Secondary advantage was that design and production groups should work in collaboration as the process for production is better understood by the design team. Various conditions may have an effect on the lean production, but the basic policies and principles would remain strong and unchanged (Baines et al., 2006). Main principles of lean production are;

1. The products with good ratings by the customers should be used for Lean production.
2. During the production process, all the steps should be included and the order of the steps should not be altered.
3. Manufacturing should follow the best available technique in the production line with confidentiality, decision making should be decentralized and all the departments must have complete information.
4. Representation to the customers should be made.

It is seen that the design and production have been given new intellect through lean production. As Baines et al (2006) say that lean production delivers various potentials for mass production and supplies with diversity in methods during the production level, design level and supply chain.

Since the last 30 years, the auto industry has been following the lean trend which is also the basis for fast growth pace of the construction productivity. Lean technique has been very effective for the auto industry. A survey conducted in 2016 by OICA (the International Organization of Motor Vehicle Manufacturers), revealed that since

2009, global car (74% automobiles) production has been growing. According to statistics, in 2016, the number of cars increased to 74 million. The car production stands on 15th position in the production activity.

During the last century the auto industry utilized three production types:

**1. Craft production:** Before industrialization, craft production system was widely used in Europe. Handmade products were represented by Craft production. The products developed were aimed at being incomparable and competent.

**2. Mass production:** In the 20th century, Ford and General Motors built units for "mass production", which was a new production system. Mass production is to manufacture the same items on a larger scale following certain mechanization and standardization.

**3. Lean production:** Taiichi Ohno and his coworker Toyoda from Toyota Motor Company in Japan came up with the notion of "lean production" in the post-Second World War reconstruction period. The main focus of the production method is that wastes get eliminated and workers are strengthened. The auto industry has risen above the level due to the application of Lean production, which brought improvisation in other industries as well.

### 3.2 Production Transitions and Lean for Production in Auto Industry

#### 3.2.1 Craft production in auto industry

In 1885, The Velozipede was developed, the first four wheeled petrol engine. Benz and Daimler, for the first time, created the automobile this year. Subsequently, auto producers proposed to create several automobile masterpieces. However, an automobile needs to be manufactured through appropriate process and organization. It was vital that the pieces be standardized. A limited numbers of automobiles were manufactured due to experienced craftsmen who were capable of mechanical design and production and fine work. Hardly few hundred cars were built (Womack et al., 2007).

Womack et al (2007) say that craft production comprises of the following features:

1. Craftsmen should be well-skilled in design and mechanic, machine operation and fitting,

2. Collection of material for automobile construction, all the parts are bought from various shops,
3. Communication amongst owner, customers, workers and suppliers should be decent,
4. Long time period for manufacture of goods was required,
5. The prices of the products were high.

### 3.2.2 Mass production in auto industry

Henry Ford, in 1908, produced the T Model design. T model was a simple smooth and inexpensive way to manufacture cars in big magnitude which are affordable as well. The task cycle, with complete fitting process, on average took 514 minutes. Few parts were left after the major part of the process was accomplished by the fitters. The first step was to gather the pieces, and then followed by placing the pieces accordingly and finally fitting them. The workers from Ford strived hard and found the parts that could be substituted. The task cycle was now reduced to 2.3 minutes (Womack & Jones, 2003). Time was further reduced to 1.9 minutes in 1913. Finally, massive productivity was achieved. During the 20s, each year 2 million cars were produced by Henry Ford. This was a massive volume of cars being produced. Ford automobiles then expanded itself. The cars were now supplied to 36 towns in USA and 19 countries. By setting the rules of mass production, it dominated the industry. Two main accomplishments were achieved, first by manufacturing an affordable car and then the transitioning from craft production to mass production.

The low prices from the model laid the foundation of the virtuous cycle of the US-American design of mass production. The continuity of the cycle can be achieved with the following critical factors:

1. The process follows the basic principles of mass production,
2. The work should be divided in such a way that each worker requires performing fewer tasks,
3. .The experts such as industrial engineers hold the sole responsibility for process improvement and process innovation,

4. Hire-and-fire strategy is followed by the human resource management and on-the-job training is conducted for acquiring the required skills,
5. “Distrust and antagonism” is found in labor while the management holds tightly the "right to manage".

### 3.2.3 Lean production in auto industry

People from Toyota visited Ford Company and General Motors (GM). Their aim was to examine the USA assembly lines and employ their rules. Consequently, few vehicles were manufactured by Toyota Company to compete in the market. (Liker, 2004)

The leaders from Toyota ,after getting disappointing result in small truck manufacturing and struggling to keep up with the market, went for a visit to Ford and General Motors to better understand the USA assembly lines and pledged to implement the Henry Ford’s book Today and Tomorrow (Liker, 2004). Following the World War II, Japan was in a state of devastation in the 50s, the automobile industry along with other industries was ruined, and the suppliers and consumers were left without finances. Eiji Toyoda and his managers (also among them was Taiichi Ohno), made a three months trip to USA to tour the auto industry, planning to learn the manufacturing process. They were astonished to know that no changes were made since the 30s in the production system. Many faults and flaws were obvious in the system, especially the fact that the system remained overcrowded with equipment, inventory, and stored materials making it difficult for the workers to perform efficiently. Toyoda and Ohnoalso identified that the system was crippled due to uneven flow, overproduction, and tiny defects which are critical were found in production batches. Once back home, Ohno was dedicated towards changing the rules of the production and employed the fundamentals of a one-piece flow system. Toyoda, Ohno and their team worked for decades on the shop floor to finally build the Toyota Production System (TPS). Other name for this system is “Lean Production”. Lean production brought a new revolution in the industry and during the last two decades, almost all industries are striving to follow the philosophy and methods of Toyota’s manufacturing and supply chain (Liker, 2004).

Lean production technique has given them the winning edge as they now are the biggest automaker in the world by dominating sales and market shares in almost all

markets around the world. Even after its factories were damaged from an earthquake and reputation was badly ripped, it soon regained its title of being the top automaker in the world. Other manufacturing industries are inquisitive of the lean thinking following continuous accomplishments by the company. Figure 3.1 indicate waste time percentage in manufacturing industry which implement lean production principles successfully (Constrcution Industry Institute, 2004).

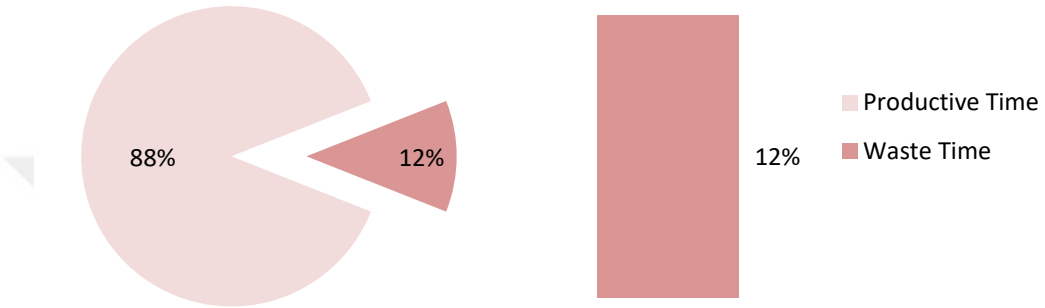



**Figure 3.1 :** Waste Time In Manufacturing Industry (Construction Industry Institute, 2004).

### 3.3 Lean Principles and Tools: 14 Principles Of Toyota Way

Fujio Cho, President of Toyota Motor Company, wrote about the key to success of Toyota in the book 'The Toyota Way' as Toyota stands out not because of any of the individual elements but rather working as a system is more important keeping all the elements intact (Liker, 2004). As Liker (2004) says that his practice must be carried out every day consistently. In order to progress in work, the Toyota Way is a system designed particularly to provide tools for 20 individuals. They are not just mere techniques for improvement and efficiency but rather it's a way to reduce inventory, and identify hidden problems, as well as, fix them with the help of workers. The 14 principles that constitute the Toyota Way are as follows (Liker, 2004):

1. Management decisions should be based on long-term goals even if small financial goals are not fulfilled: All the functions in the company should be evaluated taking into consideration its capability to generate value for the customers, employees, the company, society, and the economy.

2. Bring forward the issues through a continuous process flow: The material and information should rapidly be moved through a continuous flow, and link processes and people together for the problems to be visible immediately. A true, continuous improvement process and developing people can be brought about with the help of flow.

3. Overproduction can be avoided using “Pull” systems: During the production process, the customer should be delivered their requirements, at the right time, and in the right amount. Large inventory should not be stocked; small amounts of stock should be stored of those products that your customers really demand, this is the basic principle of Just-in-time.

4. Workload should be divided: A continuous flow can really be created by having constant workload, to eradicate unevenness in the production schedule, and by abandoning putting extra burden on people and equipment. The workload of the manufacturing and service processes should be equally divided, in place of the stop/start approach of working on projects in batches that is very commonly practiced in companies.

5. Fix the problems concurrently to achieve the right thing in the first go: To get right quality in the first attempt, it is imperative that the company philosophy be determined by halting or slowing down production in need. Eventually this will enhance the productivity of the company. Machines that have intelligence of human and are able to detect problems form the basis for creating quality.

6. Continuous improvement and employee empowerment can be achieved through standardized tasks: By gathering the information of the process ,the best practice can be standardized. Improvements should be made to the standard practice, incorporating it into the new standard in order to bring improvements continuously.

7. Visual control should be used so that all problems are visible: Simple visual systems supporting the flow and pull phenomenon should be

designed. This way a person can instantly determine if any deviation is found or the standard is being followed.

8. Thoroughly tested and reliable technology should be used that fulfils the demands of your people and processes: Technologies that conflict with culture or that might disrupt stability, reliability, and predictability should be rejected or modified. A practical test should be carried out before employing a new technology.
9. Leaders should be made who understand the work well, live the philosophy, and teach it to others: Organization should create leaders from within who know the work inside out. They should be a role model and follow company's philosophy and business attributes.
10. Exceptional people and teams who follow company's philosophy should be formed: Individuals should be explained ways to work together in teams to attain exceptional results, all the way following the company values and beliefs.
11. Give respect to your partners and suppliers by challenging them and assisting them to progress: Your success is related to the success of your suppliers and partners, so support them to reach higher and better quality, and eventually achieve success.
12. Thoroughly understand the situation by going and looking for yourself: To understand the complete situation, high level managers and executives should practice going and inspecting things for themselves rather than laying ears on what others'reports portray.
13. Decision making must be slow through consensus after considering all options and the implementation of decisions should be quick: First investigate the issue and all the potential solutions with those who are affected and collect all the data and the ideas to give opinion to form a final decision.
14. Through relentless reflections and continuous improvement, make it a learning experience: Principles that are right for your organization should be instilled and in order to achieve high performance, that

continues to add value to your customers, they should be standardized and practiced.

Fourteen principles of Toyota represented by a structure of a pyramid. The pyramid is based on the long term philosophy principle (principle 1), i.e. no quick fix or short term financial gains. the continuous process flow to eliminate waste, establish pull system, level workload, fix problems, and standardize tasks, visual control, and reliable technology (principles 2 through 8) are laid on the second level. People; grow leaders, exceptional people, and respect suppliers & partners (principles 9 to 11) are included in the third level of the pyramid. Leadership is at the top of the pyramid: go see for yourself, decision making, and learning organization (principles 12 to 14). These principles are built upon each other, and to complete the pyramid i.e. "4 P Model", Philosophy, Process, People, and Problem Solving should be accomplished. Many companies emphasize on the process or tool level while adopting lean construction, thus the long-term success with lean cannot be achieved.

Womack and Jones (2003) introduces five principles of lean thinking which depends on ideas to add value in any manufacturing company or service while minimizing waste all the way. Womack and Jones (2003) schematize Lean Thinking Principles as shown in Figure 3.2.

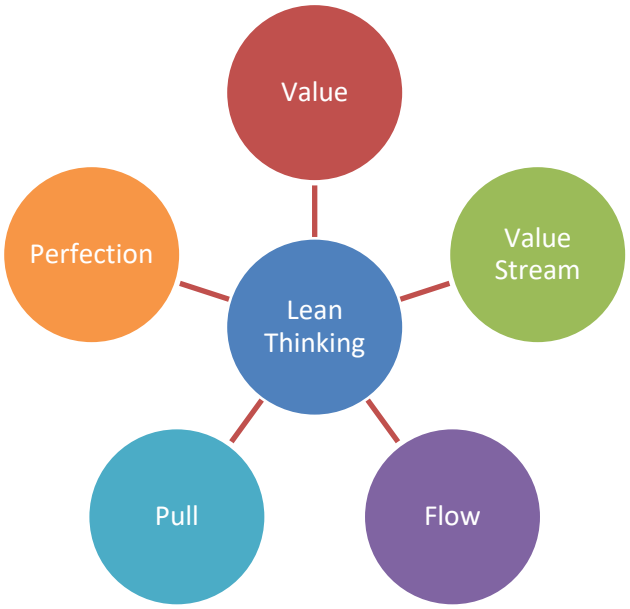



**Figure 3.2 :** The Five Lean Principles(Womack and Jones, 2003).

1. **Value:**The crucial point that lays foundation of the lean thinking is a value which is identified by the customers according to their requirements; thus the basis of this principle is on identifying value.
2. **Value stream:**This is the step that is mostly ignored by the companies, but nonetheless it has produced a large amount of waste (Liker, 2004). To achieve a specific product, the following three critical management tasks are required:
    - **Problem Solving Task**: moving from concept through detail design to production launch.
    - **Information Management Task:** moving from order taking through detailed scheduling till delivery.
    - **Physical Transformation Task:** moving from raw materials to a ready product in the customers' hand.
3. **Flow:**Flow comes after the value stream for a specific product has been stated completely and then mapped by the lean enterprise, and waste causing steps are removed. Flow is the movement of the product through one value by adding steps to the next value and keeping the product in one constant piece flow.
4. **Pull:**The capability of designing, scheduling and creating according to the desires of the customers, at the scheduled time by allowing the customers pull the required product from the manufacturer instead of pushing unwanted products (inventory).
5. **Perfection:**The last principle of lean thinking is constant improvement until perfection is achieved. In this process the efforts, time, space, cost, and mistakes are reduced and a product that the customer specifically desires, is offered. Transparency, where every aspect of the system can be visible to everyone, is a vital element in perfection. The five lean principles follow the foundation and philosophy of Lean Production as they emphasize on requirements of the customer by adding value, value stream of production to minimize waste and maximize value, keeping the production as one piece flow to reach perfection.

### 3.4 Lean Project Delivery System

The lean principle is not just limited to auto industry, instead it has been vastly adopted by other industries worldwide. Successful deployment of lean means strategic and operational benefits such as improvement in manufacturing performance, increased customer responsiveness, and financial gains.

In the high-tech industry, the probability to have had a Lean initiative in place for more than five years is 81% more when compared to others. Lean Manufacturing (LM) is considered to be an improved version of mass production. The improvements in LM are getting the product manufactured accurately in the first attempt, making improvement efforts continuously, pursuing quality in products and processes, flexible production, and waste minimizing. It is an effective tool by which the manufacturer achieves the main goal i.e. profit (Motwani, 2003). The construction industry along with any other can also employ lean thinking. The costs and program cycle times was reduced by 50% when Lockheed Martin Missile and Space Corporation employed lean practices into all their satellite production programs. When TRW Automotive Electronics Group employed lean production, labor working days were reduced by 81%, time to move raw materials was minimized by 61%, production inventory was increased by 28%, and capital expenditure decreased by 70% (Motwani, 2003). Lean principles and its applications have been adopted by several world class companies such as Boeing (largest global aerospace business), Tesco (third largest global retailer), and the U.K. Red Meat Industry at their corporate level (Simons and Zokaei, 2005).

A research was conducted by the Syme Department of Management of Monash University in collaboration with Smorgon ARC Group in Australia to explore the prospects of Australian manufacturing companies that implemented “lean production”. Sohal and Egglestone (1994) researched with fifty-one companies that were in: metal processing industry (20 %), food, beverage and tobacco industries (29 %), chemical industries (12%), automotive and transportation industries (10%) and building products industries (10%). The conclusion acquired from the study indicated that 74% of the companies that implemented lean gained a strategic advantage with the improvement curtailing from positioning in the competitive market, better customer relationships, and waste elimination and improved quality constraints.

The advantages of implementing a lean production system are increased company flexibility to fulfill the requirements of customer, the lowering of lead times, better sense of changes in the market, higher level of production, focus on performance, improved bonding with supplier and changing the management style from reactive to proactive (Sohal andEgglestone1994).

### 3.5 Main Production Problems In Construction Industry

Construction productivity is not as proficient as that of manufacturing, and the quality of construction is not up to the standards and safety conditions are quite grim (Teicholz, 2004). Few construction problems faced currently are:

- **Cost overruns:**Alternatively known as cost increase or budget overrun. It arises when the actual cost at the time of budgeting was underestimated, and consequently an unexpected cost is included in addition to the budgeted amount. Nine out of ten construction projects were found to have underestimated costs. Overruns usually ranged from 50% to 100%. All of the 20 countries and five continents covered in the study had cost underestimation; moreover the previously available data indicates that cost underestimation has not improved in the last 70 years (Flyvbjerg et al., 2002).

- **Schedule delay:** The factors causing the project delay are lack of coordination amongst engineers, lack of communication among the owner and architect, and postponed payment to general contractor and others.

- **Poor quality:** The reason given by the owners are quality of work, rework and management techniques used in the project which produced unwanted and poor results.

- **Disputes and litigations:** The cause of most issues during the projects are disputes among owners and main contractors or among the main-contractor and sub-contractors regarding claim, variation order, quality and delay of schedule.

- **Low productivity:** The Bureau of Labor Statistics recorded that the productivity of construction worker has declined by 25%, whereas other industries productivity increased up to 250 % since 1964. It was indicated in another investigation of construction industry productivity that the efficiency of average construction worker is about 40%. The main cause for lost productivity is due to the delays caused while

waiting for equipment and supplies, inefficient company processes, work rules, and overcrowded work areas.

•**Poor safety:** The sites of construction have always been hazardous. Heavy equipment and machinery are present at all the sites and if the safety precautions are inadequate, there may be accidents.

There are various problem solving methods in construction industry, such as Building Information Modelling (BIM) that prefabrication, modularization and computer integrated solutions were provided. In the construction industry, prefabrication and modularization are the processes that are several centuries old, but introduction of Building Information Modeling (BIM) and the impact of new technology have improved the project productivity because of better design and construction processes (Bernstein and Deamer, 2011). In terms of minimizing fragmentation, not much improvement was recorded, although the solutions were presented (Koskela, 2000). Koskela (2000) emphasized on the importance of theoretical foundation whose absence is a barrier to construction progress.

### 3.6 Theories of Production in Construction Industry

Construction Movement to Lean in 1993, a network of professionals and researchers in architecture, engineering, and construction (AEC) formed the International Group for Lean Construction (IGLC) that initiated practicing, educating, and researching on lean construction to solve the issues. The group emphasized on theory which wasn't a common practice. They believed that as explicit theory of construction was not practiced, it is the major holdup for the progress in the AEC field. They also believed that the explanation of the theoretical foundation of construction, along with principles and methods originating from the new foundation, would play a positive role for the renewal of the AEC industry. The IGLC aims at building a new Lean Construction methodology and alongside it, conducting annual conferences around the world to discuss the concerns that surround the construction industry.

The Lean Construction Institute (LCI) was formed in the USA in1997 for the research and to gain knowledge regarding project based production management in the design, engineering, and construction of capital facilities by maximizing the value delivered to the customer while the waste is decreased (Ballard and Howell,

2003).The definition of Lean construction given by LCI is production management based project delivery system that is based on delivering reliable and rapid customer value while not believing in the common concept that there is always a relation between time, cost and quality (Ballard and Howell, 2003).

Three major concepts of production (Transformation, Flow and Value generation) have never been used simultaneously in the 20th century; as a result, several issues were not addressed in other models (Koskela and Bertelsen, 2002).

### 3.6.1 Transformation-Flow-Value theory of production

Koskela and Bertelsen(2002) explained after studying the three theories of production that separate use of the three production concepts have been carried out and a balanced combination have not been followed, thus a good production theory wasn't achieved. Koskela created the Transformation-Flow-Value Theory of Production "TFV" by integrating the three concepts. The main focus of the TFV theory of production is on modeling, designing, controlling and improving production in all the three probable views (Koskela, 2000). Although work is being done on finding a solution but the construction problems remained intact. The solution for the construction problems can be found in the TFV theory of production.

The project management methods are usually not employed in an effective way. The TFV theory of production was intelligently developed for providing a better understanding of the construction industry and the probable solutions for improvement and also forming a new paradigm for major changes in performance. New tools and methods are needed in the construction industry to understand the need for employing the TFV production concept. Communicating the theory is important; the parties involved in the construction industry should share the experiences of the success factors, along with other issues. The main principles of TFV explained are conceptualization productions, main principles, methods and practice, practical contributions, and practical application and how each principle looks at the three different views. For instance, in practical the Transformation view focuses on the traditional work breakdown structure (WBS), while the Flow view focuses on continuous improvement and "pull" production, and Value view focuses on quality function developments (Koskela, 2000).

### 3.6.2 Integrated project delivery system (IPD)

Integrated Project Delivery system is an enterprising process that is especially designed to utilize all participants' experiences and talents involved in the project to maximize productivity. This is achieved by amalgamating people, business structures, systems and practices into an efficient free flowing process. The involved parties, stakeholders and owners by and large, demand the same project outcome as high quality for lowest possible cost and a timely completion of the project. Figure 3.3 shows Integrated Project Delivery System in which owner, engineers, architects, supliers and contractors are all co-operate and they have an equal responsibility for the success of the project, where the contractual aggrement is based on common goals and shared profit from project savings (AIA 2007).

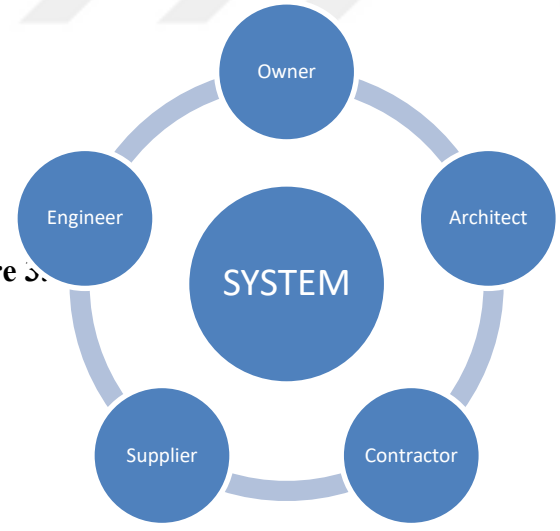



**Figure 3.** n t e g r a t e d Project Delivery System Organized Around A System, AIA 2007).

IPD aims at creating a qualified team from the inception of the project by providing guidelines, creating a trusting working environment amongst the involved parties like owners, architects, engineers, general contractor, main subcontractors, suppliers and fabricators. It provides a transparent working system which leads to efficient

decision making and makes use of state of the art technologies to achieve ascertained project success.

IPD system administers lean principles throughout the process of construction from planning to designing and constructing and helps the involved parties to achieve an increased quality and low cost value, minimize waste and optimize efficiency. It can help the owners solve many problems and hurdles in the construction process by carefully choosing a project delivery system.

Integrated Project Delivery system was developed recently in the lean construction movement, as a result of addressing the faults and disjunctions of the conventional project delivery processes, such as Design-Bid-Build and Design-Build (Kenig, et al. 2010). Application of Integrated Project Delivery is seen to optimize productivity in construction projects especially healthcare as it employs lean principles of construction. By focusing on these principles, Integrated Project Delivery involves knowledge and expertise of all the team members predominantly throughout the project, increasing the value they impart with the assistance of latest technologies.

### 3.6.3 Lean construction concept

Lean construction focuses on an environment friendly construction process by managing production until the time of delivery. It has altered the construction process for the better by extending through the basic principle of lean production system- maximum value and minimum waste- by employing specific techniques and technologies in a new project delivery process.

Selfish attitudes of some stakeholders for their own highlighted performance, affects the team negatively and weakens the project execution process on the whole. Lean construction concepts eliminate the requirement of individual performance and devise a process that flows best with team effort. It partners alliances with trade contractors with lean thinking, making the application of this concept possible. The specialty trade and supply contractors working on the field of the project come together with effective communication, collaboration and eagerness to expand and carry out the project with the least possible friction.

Lean construction concepts raise an efficient team by development of these attributes. The lean concept aims at planning management and control and results in a reliable workflow. This is achieved by (Aziz and Hafez, 2013) :

**Planning**: To devise a project specific formula for successful outcomes and planning strategies for attaining certain milestones along the way.

**Control**: Creating events along the course of construction to ensure that everything goes according to plan and improving and learning as they go onwards. It prepares the team for fluctuations in supply and engages production planning to make the transfer of responsibilities more predictable.

The lean construction process targets the following:

- Create a friendly environment for the team with responsive communication.
- Rectification of hurdles that appear in the advancement of the project.
- Optimization of performance reliability.
- Safeguarding the field team from accidents and injuries.
- Checking the durability as the project advances, leading to negligible rework and Request For Information questions.
- Reduce the need for punch lists.
- Substantial success is achieved in the project by creating accountability to understand the progress. Lean construction goals are the key to maximizing project productivity.

#### 3.6.3.1 Lean project delivery system for construction (LPDS)

Conventional project delivery systems view designers and constructors as separate entities and reserve individual roles to them. This causes conflicts among the key stakeholders of the project. It has shown to affect the project negatively with incompetent designing and documentation, time and cost overruns and frequent recurrences of rework (poor quality).

Ballard, in 2000 designed the Lean Project Delivery System to tame these adversities. The LPDS model views designers and constructors as a system and entails them to collaboratively work for the delivery of project on lean principles for maximum value and minimum wastage.

The central idea of the LPDS and the analytical criteria are adopted from the “Five Big Ideas” concept which was introduced by Forbes and Ahmed in 2010. These key

concepts revolve around a free flowing system and communication between consequent stages of the LPDS model.

To modernize the conventional project delivery model, the LPDS emphasizes on the imperative fusion of this model and “Last Planner System” (LPS). Last Planner System works around the project work packages which the production team provides and micromanages it over a short term. It is comprised of three vital planning techniques which are master pull schedule, the look ahead schedule and weekly work plan.

The value-add mechanisms of the LPS, which are detrimental in the flow of work packages, along with the worth that “ Five Big Ideas” (lean principles) impart to the LPDS will be evident in the planning techniques through the fusions in progress and how they hold an integral significance in the planning.

#### 3.6.3.2 Application of lean principles delivery system model in construction industry

Ballard (2000) defined LPDS to ensure timely delivery and to generate maximum value, LPDS model employs lean principles in various phases. Figure 3.4 explain Ballard’s model that addresses five key phases in project development system. These phases are: project definition, lean design, lean supply, lean assembly, lean use.

The ambition of this system is to optimize communication and alliances at all phases of the delivery system. This helps create neutral grounds for the parties involved creating improved relationships and a cooperative environment and effective delivery of construction projects with minimal wastage and maximized value.

**Project definition :** Similar to conventional project delivery systems, the project definition phase in LPDS behaves like a typical establishment phase. The LPDS cornerstones the consumers end by prioritizing the demands that the consumer expects from the project designers. It is an all-inclusive stage which stresses upon the underlying requirements and values of the project by early design management and extensive surveys and analysis. It is innovative with the extent of focus it has on the scope of the project. Scope helps us understand the services that the project will impart based on the consumer's requirements. This discernment lays groundwork for

the fundamental project services. This phase is composed of the following(Forbes and Ahmed, 2010) :

- An in-depth comprehension of the services and values of the project.
- The guidelines for establishing a key design.
- Generating a prototype.

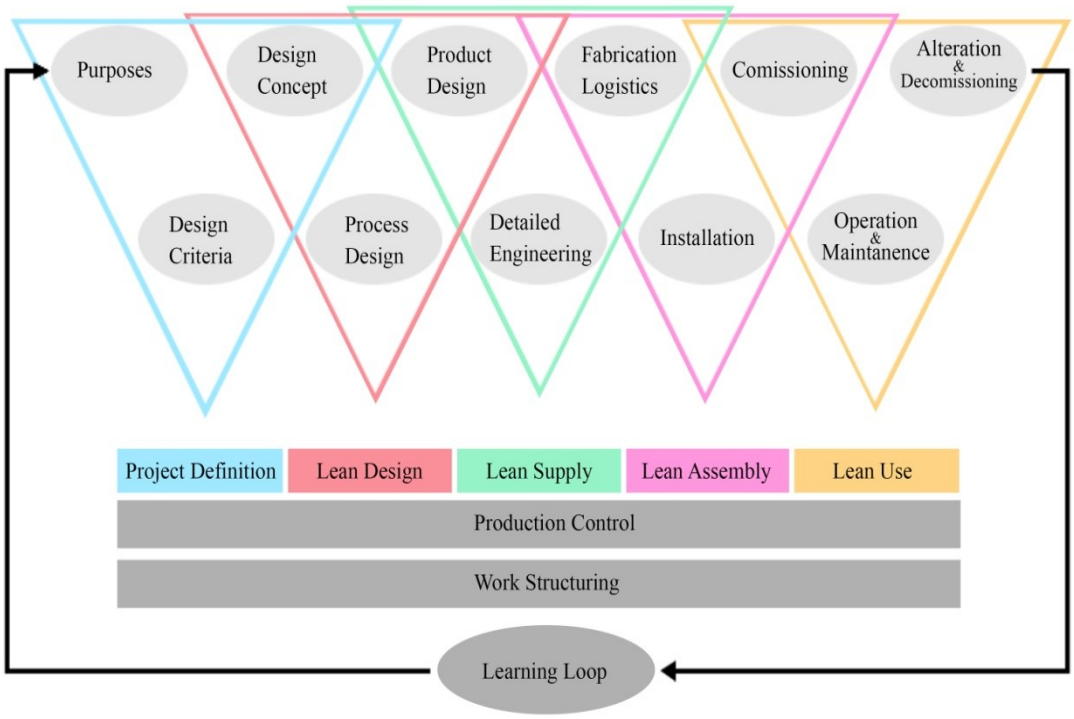



**Figure 3.4 :** Lean Project Delivery System (Ballard, 2000).

Early realization of scope and thorough analysis of the design in the definition phase helps eliminate any future discourses caused by delayed scope shifting and strife amongst contractors. It creates a smooth system which passes the jobs efficiently amongst the project team. This makes the process of definition a vital part in the timely success of the project.

**Lean design :** LPDS is an all-inclusive system which involves the contractors, suppliers, architects and engineers in an interactive relationship at the commencement stage. This helps eradicate any negativity that is otherwise expected. In the conventional systems, the designing phase is one dimensional in which the architect drafts a design and the engineer executes the parameters (i.e. structural components). This gives rise to communication gaps in corresponding procedures.

Architects may disregard the constructors' risks in their designs. This gives rise to a dissonance in the designing for the product with no harmony to the process. This results in friction as the project progresses and naturally creates delays in the delivery of each milestone. LPDS particularly acknowledges this communication barrier. It instead represents these characteristics as interlocking triangles which eradicates the communication gap creating a rational model. This way, the purpose is not only problem solving, but to avoid it altogether by creating harmonious decision making strategy.

**Lean supply :** Lean supply phase addresses the relation between supply and its effect on the execution of the model design. Using the LPDS system, a comprehensive analysis of the product and process is carried out which helps in determining the supply of material and the manner in which it affects the project advancement. It entails an interactive relationship with the suppliers and includes them in the project earlier on so that the inclination of the supplier is towards the project. In other case, the supplier's disregard the master schedule and how it affects the project and delivery times. More often than not, the storage facilities of the material are not up to the mark, which is key reason of wastage and pilferage. LPDS brings into effect three main solutions to these problems: improving workflow reliability, creating a transparent system using web based management software across the value streams and relating production workflow with material supply (Forbes and Ahmed, 2010).

**Lean assembly :** Lean assembly is the part of lads where all the theoretical measurements are applied practically. This is the phase which overcomes the most turbulent circumstances in the establishment of the rigorous designing, planning and scheduling which is carried out in an extensive period. The lean principles applied in this phase are dominant in the execution of prefabrication Construction Techniques. The assembly phase involves the principles of LPDS through logistics to fabricators and through physical installation and commissioning. Therefore, this phase has the most resilient work schedules and production control for a coherent assembly system.

The 'last Planner System' is a major asset at this point in production. One can hugely benefit from it for assuming flow and control over the project affairs. The planner helps in creating strict control on performance and material supply which gives a

resilient control on the performance for timely delivery and makes way for improvements in the commissioning phase. Keeping customer satisfaction in mind during the commissioning phase assures of the quality and deadlines. This helps in creating a positive ambience till the completion of the project and makes timely deliveries possible (Forbes and Ahmed, 2010).

**Lean Use :** The building is tested for its effective provision of services it is meant to yield to the customer. To check whether or not the building satisfies the customer's briefing, the Post Occupation Evaluations (POE) are carried out. POEs provide a scoring method for various aspects, providing an assessable data which gives an overview of the structure's quality. This data can be used to address the problem sites and enhance environment quality. These steps are termed as 'learning loops' which play an important role in understanding the execution of the project construction and decision making. This helps us understand whether the client is satisfied with the results and helps us evaluate the extent of success of the project (Forbes and Ahmed, 2010).

The "Last Planner System" bridges the communication to workflow in a "lean project delivery system". It serves the LPDS through all the 5 stages of the LPS. The conventional delivery systems are less practical as they focus on intervals and urgency of tasks rather than viewing the hindrances that may occur in carrying them out. This untimely realization of hurdles results in delays and reworks. Ballard (2000) redefined this concept and involved the subsidiary parties (e.g. foremen, subcontractor etc.) in a manner that allows them to make decisions regarding execution of the project. This enables them to stay around materials and resources which they consider best and suitable for the execution of the project. With the help of LPS the decision making body is the one performing the task (Forbes and Ahmed, 2010).

In a nutshell, LPS functions on a ground of collaboration, teamwork, communication, empowerment and ownership which creates modern standards for scheduling (Mossman, 2009).To make the LPS successful, the following tools are engaged:

**The Master Pull schedule:** a list of agendas which are to be achieved as per a time table. It holds future plans and ensures that the project is going according to the plan.

**The look ahead schedule**: it can be considered a subdivision of Master full schedule as it divides the task across a span of 6-8 weeks. It is vital to assigning tasks and prioritizing the workflow.

**The work plan**: which is further divided into Weekly Work Plan (WWP) and Daily Work Plans (DWP). These are short term work plans which are to be executed over the period of a week or a day.

These schedules play a vital role in each project's requirements and it is not a 'one size fits all'. All the involved parties should be allowed their due participation in the sequencing of the schedules.

### 3.7 Summary of Lean Construction

Lean construction modeling has emerged from the hindrances of conventional modeling concepts. It is a set of state-of-the-art managing systems and sequencing tools and techniques which are foundation for the metamorphosis of the commonly practiced modeling techniques. "Lean project Delivery system" along with the "last Planer System" provides basic groundwork for the application of lean construction models in the construction industry. The "Five Big Ideas" concept which are lean thinking principles; value, value stream, flow, pull and perfection definitions (Forbes and Ahmed, 2010) provide anchorage to the principles for the practical application of LPDS and LPS and opens new corridors for innovative techniques. As a result of implementing lean principles in manufacturing industry, waste time rate decrease 12% in production process according to the report of Construction Industry Institute (2004) but, waste time rate in construction process without implementing lean principles is stated as 57% for construction industry in the same report.

Lean thinking principles identify value of customer expectations to product needed or wanted production to avoid wastes; feasibility and applicability of tasks to detail production stream; maps of production steps to keep the product in one constant piece flow;capability of designing, scheduling and creating according to the desires of the customers at scheduled time; the efforts, time, space, cost and mistakes to reduce them for producing the customer's specifially desired product. However, construction productivity is not as sufficient as that of manufacturing, and quality of construction is not up to the standards. Construction industry still face to few

problems that are exceeded by manufacturing industry, such as cost overruns, schedule delay, poor quality, disputes and litigations, low productivity and poor safety.

Lean construction concept focuses on maximum value and minimum waste by extending through the basic five principles of lean production system until the delivery time of project. The lean constrcution consept aims at management plan, control and results in a reliable workflow to eliminate waste of project resources.

# 4. MAIN WASTE TYPES IN TURKISH CONSTRUCTION INDUSTRY

For identifying main waste types in Turkish Construction Industry, interviews were organized with 5 construction companies in order to analyze the waste causes in Turkish Construction Industry, interviews are carried out in relation with the main waste causes discussed in second chapter. During the interviews, Questions given in Appendix A are asked to the respondents. Further, identified waste causes provided by the respondents are classified and matched in accordence with Taiichi Ohno's seven waste classification to provide compatible results with lean construction principles.

## 4.1 Interviews for Identification of Main Waste Types in Turkish Construction Industry

Within the scope of Lean Construction Techniques, waste resources that cause delay and material loss in the construction industry are covered under 7 headings as transformation waste, inventory waste, motion waste, over-processing waste, over-production waste and correction waste.

Depending on their experiences, the waste causes are asked to Respondents (1 = Not Effective, 2 = Unstable, 3 = Slightly Effective, 4 = Effective, 5 = Absolutely Effective) to determine the effectiveness of the waste causes. Tables 4.1 shows the profiles of the respondents and the classification of companies associated with their responses.

1st company (1C) works with a multidisciplinary team in international projects and it is well-experienced in mix-used projects. 2nd company (2C) is an national contractor and well-experinced for mass-housing and residential construction projects. 3rd company (3C) is an international consultant firm for superstructures. 4th company (4C) is a large architectural firm and it works as consultant and construction supervisor. 5th company is a small subcontractor firm in national residential projects.

**Table 4.1:** Information Of Respondents

| Roles | Company Type | Experience Year | Knowledge For Lean Construction | Knowledge For BIM |
|---|---|---|---|---|
| Site Manager | International Contractor (1C) | 8 | × | √ |
| Site Architect | National Contractor (2C) | 6 | × | √ |
| Project Manager | International Contractor (3C) | 12 | × | × |
| Consultant Architect | International Consultant (4C) | 10 | √ | √ |
| Site Engineer | National Contractor (5C) | 3 | √ | × |

According to the views of participants, Figure 4.1 shows the effectiveness of the waste causes of Turkish construction industry in seven distinct waste causes according to lean principles.The correction waste causesare the most effective one with 3.57 over 5, while the transformation waste causes is 3,02. The second effective waste cause is waiting waste with 3.55 while motion waste is 3,49. Over-production and over-processing wastes are with 3,45 and 3,40 scores. Overall it is clear that inventory and transformation waste causes are the slightly effective ones with 3,20 and 3,02 amount in 5 for Turkish construction industry. It is seen that transformation and inventory waste causes have the least effect in Turkish Construction Industry.

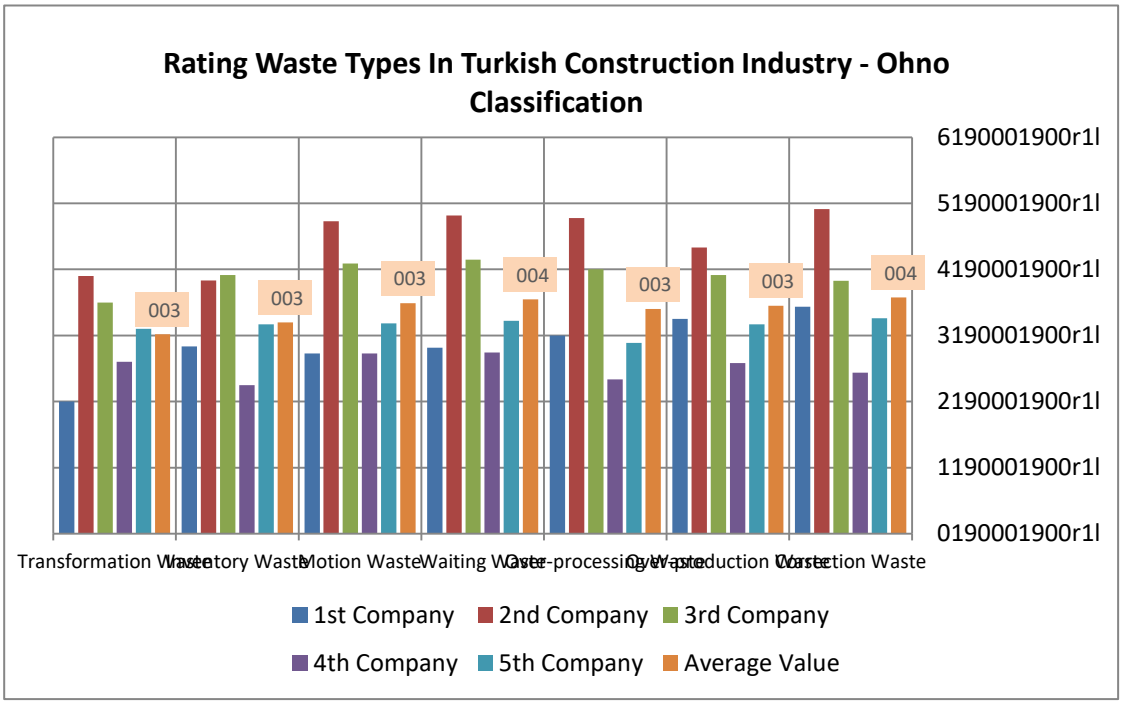



**Figure 4.1 :** Waste Types Distribution In Turkish Construction Industry

## 4.2 Analysis of Construction Waste Causes In Turkey

### 4.2.1 Transformation waste causes

Transformation waste causes have the lowest effect among construction wastes in Turkey. As shown in Table 4.2, inefficient planning and programming of the project and repetition of work due to design changes and revisions have great efficiency with 4,4 and 4,0 among all other transformation waste causes. These two causes can be reduced by using lean principles and alternative ways.

**Table 4.2:** Transformation Waste Causes In Turkish Construction Industry

| Transformation Waste In Turkish Constrcution Industry | | | | | | | |
|---|---|---|---|---|---|---|---|
| **No** | **Waste Causes** | **1C** | **2C** | **3C** | **4C** | **5C** | **Average Value** |
| 1 | Inefficient planning and programming of the project | 5 | 4 | 5 | 4 | 4 | 4,4 |
| 2 | Repetition of work due to design changes and revisions | 3 | 5 | 5 | 2 | 5 | 4 |
| 3 | Losses in loading / unloading / stacking operations | 2 | 4 | 4 | 3 | 3 | 3,2 |
| 4 | Not having workforce for required work | 1 | 4 | 3 | 3 | 4 | 3 |
| 5 | Damage of materials during moving in site | 2 | 3 | 3 | 3 | 3 | 2,8 |
| 6 | Damage of material during transportion to the worksite | 2 | 3 | 3 | 3 | 3 | 2,8 |
| 7 | Unnecessary displacement of material on site | 2 | 4 | 3 | 3 | 2 | 2,8 |
| 8 | Reaching concrete from far away to the construction site | 1 | 4 | 4 | 2 | 2 | 2,6 |
| 9 | Unnecessary length of way to material source | 1 | 4 | 3 | 2 | 2 | 2,4 |
| 10 | Transportation due to insufficient transportation system | 1 | 4 | 2 | 1 | 3 | 2,2 |

### 4.2.2 Inventory waste causes

Inventory srategies causes remarkable waste in construction fields all around the world, as well as in the Turkish construction industry. Results of the interviews illustrates that inventory waste reasons are slightly effectivecompared to others. AsTable 4.3 shows lack of experience of teams, material requirement program not being performed properly and material stock made without paying attention to the work schedule are the waste causes that should be taken in to consideration with lean construction.

**Table 4.3:** Inventory Waste Causes In Turkish Construction Industry

**Inventory Waste In Turkish Construction Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Lack of experience of teams | 3 | 4 | 5 | 3 | 4 | 3,8 |
| 2 | Material requirement program not being performed properly | 4 | 4 | 5 | 2 | 3 | 3,6 |
| 3 | Material stock made without paying attention to the work schedule | 3 | 4 | 5 | 2 | 4 | 3,6 |
| 4 | Insufficient level of supervision | 3 | 3 | 5 | 3 | 3 | 3,4 |
| 5 | Insufficient space for storage of materials | 3 | 4 | 5 | 2 | 3 | 3,4 |
| 6 | Delay in delivery of materials | 3 | 4 | 4 | 2 | 3 | 3,2 |
| 7 | Excessive material intake and storage | 2 | 4 | 4 | 2 | 4 | 3,2 |
| 8 | Finding poor quality materials that will not be used in production | 3 | 4 | 3 | 2 | 4 | 3,2 |
| 9 | Excess inventory because of making the production inappropriately for the schedule | 4 | 3 | 3 | 2 | 3 | 3 |
| 10 | Lack of weekly project evaluation meetings | 3 | 4 | 3 | 2 | 2 | 2,8 |
| 11 | No material in operation site | 1 | 4 | 3 | 3 | 3 | 2,8 |
| 12 | Possession of materials not approved by the administration | 2 | 4 | 2 | 2 | 2 | 2,4 |

### 4.2.3 Motion waste causes

Unnecessary work actions create time and cost wastes for stakeholders and this kind of wastes has the amount of effectiveness with 3,49 (Figure 4.1). As seen in Table 4.4,eleven motion waste causes are asked to the construction or project managers. Only spent time on employee needs among them has a value less than 3.0 that means its position is unstable for constrcution industry, on the other hand, other ten causes have serious negative effects on waste management of construction industry in Turkey. Waste causes of inadequate and faulty project coordination has the highest score when compared to others. Unrealistic work plan, frequent revisions in drawings or designand incorrect selection of construction methodare the other causes of motion wastes that have an average value of 4 over 5. Precautions shoul be taken for them.

**Table 4.4:** Motion Waste Causes In Turkish Construction Industry

**Motion Waste In Turkish Constrcution Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Inadequate and faulty project coordination | 4 | 5 | 5 | 3 | 4 | 4,2 |
| 2 | Frequent revisions in drawings or design | 3 | 5 | 5 | 4 | 3 | 4 |
| 3 | Incorrect selection of construction method | 2 | 5 | 5 | 4 | 4 | 4 |
| 4 | Unrealistic work plan | 4 | 5 | 5 | 3 | 3 | 4 |
| 5 | Lack of communication between site teams | 3 | 5 | 4 | 2 | 3 | 3,4 |
| 6 | Lost time due to subcontractor (labor transport, material handling, etc.) | 3 | 5 | 5 | 2 | 2 | 3,4 |
| 7 | Loss of time for employees to access equipment | 2 | 4 | 3 | 3 | 4 | 3,2 |
| 8 | Loss of time for employees to reach the workplace | 3 | 4 | 3 | 3 | 3 | 3,2 |
| 9 | Time lost for transportation in site | 2 | 4 | 4 | 2 | 4 | 3,2 |
| 10 | No tools and equipment for required work | 2 | 5 | 4 | 2 | 2 | 3 |
| 11 | Spent time on employee needs (dining hall, WC, smoking, etc.) | 2 | 5 | 2 | 2 | 3 | 2,8 |

### 4.2.4 Waiting waste causes

Delay in construction are generally reason of waiting time for actions. Waiting for work conditions is the most effective reason of wastes with 3,55 amount of effectiveness on construction waste after correction waste types. These waste types are directly related with project schedule and managers' work plans and all kind of stakeholders could be responsible for waiting wastes that are the unavoidable for every construction industry because every ordinary or extraordinary changes in work influence the project's implementation plans. Table 4.5 includes twenty-seven causes of waiting for the evaluation of how waiting causes effects construction in Turkey. There are four waste causes with 4 over 5 and these causes covers all project stakeholders. Disputes that cause client/consultants to stop work, construction faults made by site teams, frequent revisions in drawings or design and construction difficulty due to design are four main waste causes that are planned by client/consultants, subcontractors, project offices and contractors. Twenty-four waiting causes have an average value of more than 3. That means their effectiveness is serious and proves lack of communcation and coordination between stakeholders in Turkish construction industry.

**Table 4.5:** Waiting Waste Causes In Turkish Construction Industry

**Waiting Waste In Turkish Constrcution Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Construction difficulty due to design | 4 | 5 | 5 | 3 | 3 | 4 |
| 2 | Construction faults made by site teams | 4 | 5 | 4 | 2 | 5 | 4 |
| 3 | Disputes that cause client / consultants to stop work | 4 | 5 | 5 | 3 | 3 | 4 |
| 4 | Frequent revisions in drawings or design | 3 | 5 | 5 | 4 | 3 | 4 |
| 5 | Delay of material supply | 3 | 5 | 4 | 3 | 4 | 3,8 |
| 6 | Insufficient level of supervision | 4 | 5 | 5 | 2 | 3 | 3,8 |
| 7 | Irregular cash flow | 2 | 5 | 5 | 3 | 4 | 3,8 |
| 8 | Lack of craftmen quality | 3 | 5 | 5 | 2 | 4 | 3,8 |
| 9 | Lack of experience of teams | 3 | 5 | 4 | 2 | 5 | 3,8 |
| 10 | Lack of money incentive | 2 | 5 | 5 | 3 | 4 | 3,8 |
| 11 | The slow progress of the decision-making process | 2 | 5 | 5 | 3 | 4 | 3,8 |
| 12 | No periodic meetings between management, contractors and site staff | 4 | 5 | 5 | 3 | 2 | 3,8 |
| 13 | Unrealistic work plan | 3 | 5 | 5 | 3 | 3 | 3,8 |
| 14 | Inadequate and faulty project coordination | 3 | 5 | 5 | 2 | 3 | 3,6 |
| 15 | Inadequate instructions provided by the supervisor | 3 | 4 | 4 | 4 | 3 | 3,6 |
| 16 | Slow progress of the maintenance process in case of failure | 3 | 4 | 5 | 3 | 3 | 3,6 |
| 17 | Waiting for replacing materials that do not meet the project requirements specified in the design files | 2 | 5 | 5 | 3 | 3 | 3,6 |
| 18 | Communication problem between teams and supervisor | 3 | 5 | 4 | 2 | 3 | 3,4 |
| 19 | Delay in equipment transportation or installation | 2 | 5 | 3 | 3 | 4 | 3,4 |
| 20 | Lack of communication between site teams | 3 | 5 | 4 | 3 | 2 | 3,4 |
| 21 | Process slowdown due to differences in drawings | 2 | 5 | 3 | 4 | 3 | 3,4 |
| 22 | Weather conditions that prevent work | 5 | 4 | 3 | 3 | 2 | 3,4 |
| 23 | Bureaucratic procedures | 2 | 5 | 4 | 3 | 2 | 3,2 |
| 24 | Absence of teams | 2 | 5 | 3 | 1 | 4 | 3 |
| 25 | Ignore craftmen's suggestions / ideas | 2 | 5 | 2 | 2 | 3 | 2,8 |
| 26 | Job accidents that prevent work | 2 | 4 | 3 | 2 | 2 | 2,6 |
| 27 | Job walkout | 1 | 4 | 2 | 3 | 3 | 2,6 |

### 4.2.5 Over-processing waste causes

Over-processing waste occurs where inappropriate construction techniques and equipments are used. Also, worked with too tight quality tolerances, and inessential construction operations required by the customer. Causes of over-processing waste has average effectiveness of 3,40. These causes happen as a result of experience weakness of construction stakeholders as seen in Table 4.6.

**Table 4.6:** Over-production Waste Causes In Turkish Construction Industry

**Over-processing Waste In Turkish Constrcution Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Lack of weekly project evaluation meetings | 3 | 5 | 4 | 3 | 4 | 3,8 |
| 2 | No periodic meetings between management, contractors and site staff | 3 | 5 | 4 | 3 | 3 | 3,6 |
| 3 | Unrealistic work plan | 3 | 5 | 5 | 2 | 3 | 3,6 |
| 4 | Inadequate instructions provided by the supervisor | 3 | 5 | 5 | 1 | 3 | 3,4 |
| 5 | Incorrect selection of construction method | 2 | 5 | 4 | 3 | 3 | 3,4 |
| 6 | Insufficient level of supervision | 3 | 5 | 5 | 2 | 2 | 3,4 |
| 7 | Lack of experience of teams | 3 | 5 | 5 | 2 | 2 | 3,4 |
| 8 | Job accidents that prevent work | 3 | 4 | 2 | 3 | 3 | 3 |
| 9 | Lack of team spirit in and between teams | 4 | 4 | 2 | 2 | 3 | 3 |

### 4.2.6 Over-production waste causes

Over-production is the most serious waste type in manufacturing industry due to beginning of mass production. However this waste type is in the fourth rank with 3,45. According to Table 4.7, as a result of interviews, main reason of over production waste causes is unrealistic work plan with average value of 4.2.

**Table 4.7:** Over-production Waste Causes In Turkish Construction Industry

**Over-production Waste In Turkish Constrcution Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Unrealistic work plan | 3 | 5 | 5 | 5 | 3 | 4,2 |
| 2 | Construction faults made by site teams | 3 | 5 | 3 | 3 | 4 | 3,6 |
| 3 | Inadequate and faulty project coordination | 3 | 5 | 5 | 1 | 4 | 3,6 |
| 4 | No periodic meetings between management, contractors and site staff | 4 | 4 | 4 | 3 | 3 | 3,6 |
| 5 | Site area congestion | 4 | 4 | 4 | 3 | 3 | 3,6 |
| 6 | Insufficient level of supervision | 3 | 4 | 5 | 2 | 3 | 3,4 |
| 7 | Lack of experience of teams | 4 | 4 | 4 | 3 | 2 | 3,4 |
| 8 | Lack of weekly project evaluation meetings | 3 | 4 | 4 | 3 | 3 | 3,4 |
| 9 | Inadequate instructions provided by the supervisor | 3 | 4 | 3 | 2 | 4 | 3,2 |
| 10 | Incorrect selection of construction method | 2 | 5 | 4 | 2 | 3 | 3,2 |
| 11 | Lack of team spirit in and between teams | 3 | 4 | 2 | 3 | 4 | 3,2 |
| 12 | Insufficient space for storage of materials | 4 | 4 | 4 | 1 | 2 | 3 |

### 4.2.7 Correction waste causes

Quality expectations of clients or revisions and additions to project drawings are the main reasons of correction wastes. As a result of interviews, correction wastes has the highest value of 3,57, when compared with others.

**Table 4.8:** Correction Waste Causes In Turkish Construction Industry

**Correction Waste In Turkish Constrcution Industry**

| No | Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|
| 1 | Frequent revisions to drawings or designs cause additional work or rework | 4 | 5 | 5 | 3 | 4 | 4,2 |
| 2 | Inadequate payments or no payment | 5 | 5 | 4 | 3 | 4 | 4,2 |
| 3 | Project faults | 4 | 5 | 4 | 3 | 5 | 4,2 |
| 4 | Waiting for replacing materials that do not meet the project requirements specified in the design files | 4 | 5 | 5 | 3 | 4 | 4,2 |
| 5 | Communication problem between teams and supervisor | 4 | 5 | 3 | 3 | 4 | 3,8 |
| 6 | Construction faults made by site teams | 3 | 5 | 4 | 3 | 3 | 3,6 |
| 7 | Inadequate and faulty project coordination | 3 | 5 | 5 | 2 | 3 | 3,6 |
| 8 | Insufficient level of supervision | 3 | 5 | 5 | 2 | 3 | 3,6 |
| 9 | Lack of experience of teams | 3 | 5 | 4 | 2 | 4 | 3,6 |
| 10 | Process slowdown due to differences in drawings | 4 | 5 | 4 | 2 | 3 | 3,6 |
| 11 | The slow progress of the decision-making process | 5 | 5 | 3 | 2 | 3 | 3,6 |
| 12 | Unrealistic work plan | 3 | 5 | 5 | 2 | 3 | 3,6 |
| 13 | Construction difficulty due to design | 2 | 5 | 5 | 1 | 4 | 3,4 |
| 14 | Disputes that cause client / consultants to stop work | 4 | 5 | 3 | 3 | 2 | 3,4 |
| 15 | Ignore craftmen's suggestions / ideas | 4 | 5 | 3 | 2 | 3 | 3,4 |
| 16 | Inadequate instructions provided by the supervisor | 3 | 4 | 3 | 3 | 4 | 3,4 |
| 17 | Incorrect selection of construction method | 3 | 5 | 4 | 3 | 2 | 3,4 |
| 18 | Lack of money incentive | 3 | 5 | 4 | 2 | 3 | 3,4 |
| 19 | Poor quality of materials | 4 | 4 | 3 | 2 | 4 | 3,4 |
| 20 | Lack of communication between site teams | 3 | 5 | 3 | 2 | 3 | 3,2 |
| 21 | No periodic meetings between management, contractors and site staff | 3 | 5 | 3 | 3 | 2 | 3,2 |
| 22 | No tools and equipment for required work | 3 | 5 | 3 | 3 | 2 | 3,2 |
| 23 | Absence of teams | 2 | 5 | 3 | 2 | 3 | 3 |

It is seen in Table 4.8, absence of teams in correction waste causes has the lowest average value of 3 while the highest values of waste causes are waiting for replacing materials that do not meet the project requirements specified in the design files, frequent revisions to drawings or designs cause additional work or rework, project

faults and inadequate payments or no payment with 4.2. That means expectations of customers are not properly satisfied in these manners

### 4.2.8 Assessment of findings

In this section, the results of interviews carried out to analyze waste types in Turkish Construction Industry. The results reveal that there is a lack of project delivery and organization skills. Contrary to the development of manufacturing industry, conventional project management methods still have been used more than innovative choices for construction project management and important construction companies are managed based on personal experience. According to respondents, main waste causes have average value of 3.5 ove 5 are presented in Table 4.9. The wast causes occur due to design, operation and procurement problems.The most common waste cause is insufficient planning and programming of the project..

**Table 4.9:** Main Waste Causes In Turkish Construction Industry

| Sources | No | Main Waste Causes | 1C | 2C | 3C | 4C | 5C | Average Value |
|---|---|---|---|---|---|---|---|---|
| Operation | 1 | Inefficient planning and programming of the project | 5 | 4 | 5 | 4 | 4 | 4,4 |
| Design | 2 | Frequent revisions to drawings or designs cause additional work or rework | 4 | 5 | 5 | 3 | 4 | 4,2 |
| Design | 3 | Inadequate and faulty project coordination | 4 | 5 | 5 | 3 | 4 | 4,2 |
| Others | 4 | Inadequate payments or no payment | 5 | 5 | 4 | 3 | 4 | 4,2 |
| Design | 5 | Project faults | 4 | 5 | 4 | 3 | 5 | 4,2 |
| Design | 6 | Construction difficulty due to design | 4 | 5 | 5 | 3 | 3 | 4 |
| Others | 7 | Disputes that cause client / consultants to stop work | 4 | 5 | 5 | 3 | 3 | 4 |
| Design | 8 | Frequent revisions in drawings or design | 3 | 5 | 5 | 4 | 3 | 4 |
| Operation | 9 | Incorrect selection of construction method | 2 | 5 | 5 | 4 | 4 | 4 |
| Design | 10 | Repetition of work due to design changes and revisions | 3 | 5 | 5 | 2 | 5 | 4 |
| Operation | 11 | Unrealistic work plan | 4 | 5 | 5 | 3 | 3 | 4 |
| Operation | 12 | Construction faults made by site teams | 4 | 5 | 4 | 2 | 5 | 4 |
| Operation | 13 | Communication problem between teams and supervisor | 4 | 5 | 3 | 3 | 4 | 3,8 |
| Procurement | 14 | Delay of material supply | 3 | 5 | 4 | 3 | 4 | 3,8 |
| Operation | 15 | Insufficient level of supervision | 4 | 5 | 5 | 2 | 3 | 3,8 |
| Others | 16 | Irregular cash flow | 2 | 5 | 5 | 3 | 4 | 3,8 |
| Others | 17 | Lack of craftmen quality | 3 | 5 | 5 | 2 | 4 | 3,8 |
| Operation | 18 | Lack of experience of teams | 3 | 4 | 5 | 3 | 4 | 3,8 |
| Others | 19 | Lack of money incentive | 2 | 5 | 5 | 3 | 4 | 3,8 |
| Operation | 20 | Lack of weekly project evaluation meetings | 3 | 5 | 4 | 3 | 4 | 3,8 |
| Operation | 21 | No periodic meetings between management, contractors and site staff | 4 | 5 | 5 | 3 | 2 | 3,8 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Operation | 22 | The slow progress of the decision-making process | 2 | 5 | 5 | 3 | 4 | 3,8 |
| Operation | 23 | Inadequate instructions provided by the supervisor | 3 | 4 | 4 | 4 | 3 | 3,6 |
| Procurement | 24 | Material requirement program not being performed properly | 4 | 4 | 5 | 2 | 3 | 3,6 |
| Procurement | 25 | Material stock made without paying attention to the work schedule | 3 | 4 | 5 | 2 | 4 | 3,6 |
| Operation | 26 | No periodic meetings between management, contractors and site staff | 3 | 5 | 4 | 3 | 3 | 3,6 |
| Design | 27 | Process slowdown due to differences in drawings | 4 | 5 | 4 | 2 | 3 | 3,6 |
| Operation | 28 | Slow progress of the maintenance process in case of failure | 3 | 4 | 5 | 3 | 3 | 3,6 |
| Procurement | 29 | Waiting for replacing materials that do not meet the project requirements specified in the design files | 2 | 5 | 5 | 3 | 3 | 3,6 |

All design, procurement and operational problem causes can be prevented by implementing proper Lean Principles and BIM. Lean Construction Techniques includes early warning and feedback systems for reducing wastes to provide more profit and customer expectations. On the other hand, Turkish construction companies prefer to increase profit percentage for recycling of money loss rather than using effective project management methods or software. As another solution for decreasing losses, they share risk of projects or they upload all risk to contractors and sub-contractors.

In addition, making unrealistic work plan and projection is the other key and common factor that causes waste in Turkish construction industry. In Turkish construction market, conventional project planning methods are generally used for forming experience based project schedules that contain construction phases step by step with two-dimensional ways. However, integrated project delivery system and softwares are developed for simulating a real-time model of project and construction process that entire system and program approaches are known as BIM.

Eliminating and/or reducing waste causes will increase the satisfaction of all parties. An attempt to integration of lean principles with BIM may be heplful in this manner.

## 5. AN APPROACH TO LEAN & BIM BASED WASTE MANAGEMENT

Research of Forbes and Ahmed (2010) reveals that implementing Lean Construction Methods increases the quality and productivity of constrcution projects about 77%. In addition, researches of Alwi (2003) showed that implementation of Lean Construction Methods improves working conditions at the construction sites by decreasing physical and psychological stress.

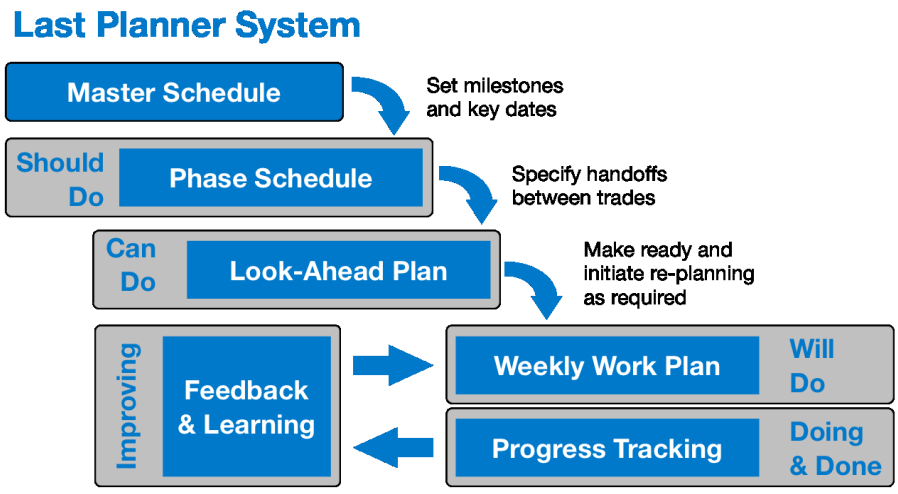
### 5.1 Lean Construction Methods (LCM)

There are twenty one main lean construction methods have been implemented in projects partly or totally in construction industries . These main methods are;

**The Last Planner System (LPS) :**LPS was a strategy that structures work process and manages project variability (Ballard and Howell, 1994).To accomplish lean objectives of decreasing waste, rising efficiency, and reducingunpredictability, for the most part through a social procedure, by trying to make arranging a common attempt and by rising the reliabilityof the dedication of team members. Figure 5.1 shows phases of Last Planner System.

**Figure 5.1 :** Last Planner System

**Value Stream Mapping (VSM) :**VSM sets up the present condition of the development procedure or inventory network to recognize the wastes. The future state



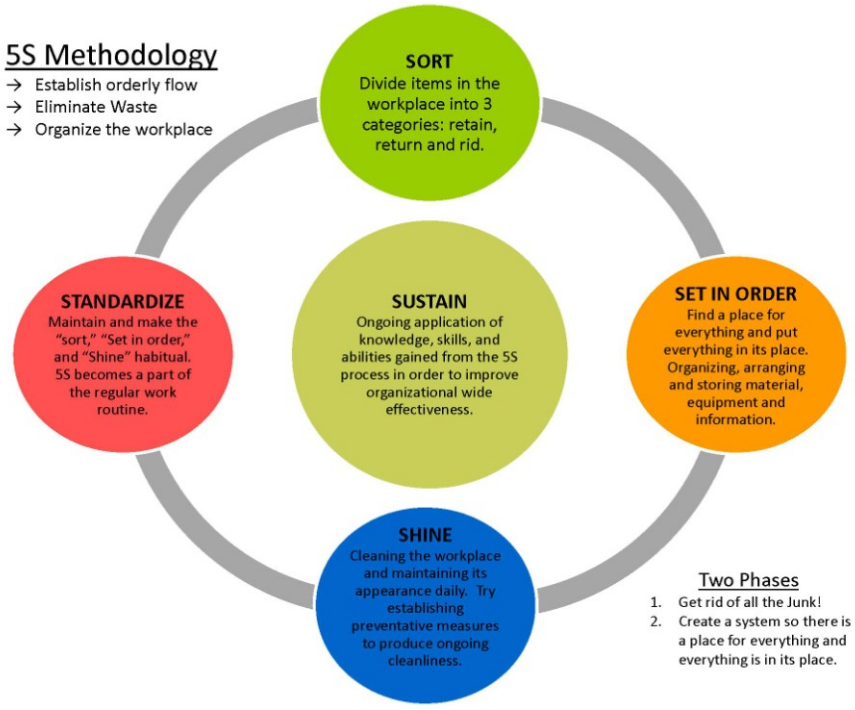

creates change and develop techniques (Arleroth and Kristensson, 2011).

**Standardized Work :**Adaptable regimentation lean construction tool including the improvement of a typical path for performing particular construction processes in light of the accessible confirmation (Toussaint and Berry, 2013).

**The 5S Process :**The 5Ss are arranging, fixing, sparkling, institutionalizing, and maintaining the facilities and processes utilized as a part of construction. The 5S processrises the efficiency of the task since it lessens the time spent looking for provisions, instruments, and equipment etc. As shown in Figure 5.2, the 5S Process cycle includes sort, set in order, shine, standardize and sustain phaseses.

**Figure 5.2 :** 5S Methodology

**Kaizen :**To accomplish lean objectives of diminishing waste, increasing profitability, and diminishing unpredictability. By endeavoring to make arranging a shared attempt




and by rising the dependability of the responsibility of team members. LPS was a technique that structures work process and manages project variability (Ballard and Howell, 1994).

**Total Quality Management :**The majority of the significant tools used to address construction execution issues depend on the idea of plan-do-act. Functions include

identification and assessment of the issue, creating, and executing solutions, and assessing and estimating the outcomes(Marosszeky, 2002).

**Increased visualization :**Conveying key data successfully to the workforce through posting different signs and labels around the building site; specialists can remember components, for example, work process, execution targets, and particular required activities in the event that they over and over observe them (Conte and Gransberg, 2001).

**Fail Safe for Quality and Safety :**That is a lean construction tool that guarantees no damage or least is maintained in case of particular disappointments(Ogunbiyi, 2014).

**Daily Huddle Meetings :** Two-way communication ways are the most important tool to obtain full motivation of employees and the key factor is the daily huddle meeting process (Ogunbiyi, 2014).

**First run studies :**First-run studies are used to redesign vital assignments. Activities are investigated altogether, and ideas and proposals are raised to investigate elective methods for doing the task. The PDCA (design, do, check, and act) cycle is utilized to develop the first-run study(Ogunbiyi, 2014).

**The Five Why's :**The Five Why's is the lean development iterativequestion-asking procedure that explains "cause-andeffect" components related with an issue. Figure 5.3 explain that each Why? For problem and symptom provide to solve identified problem step by step (Aziz and Hafez, 2013).

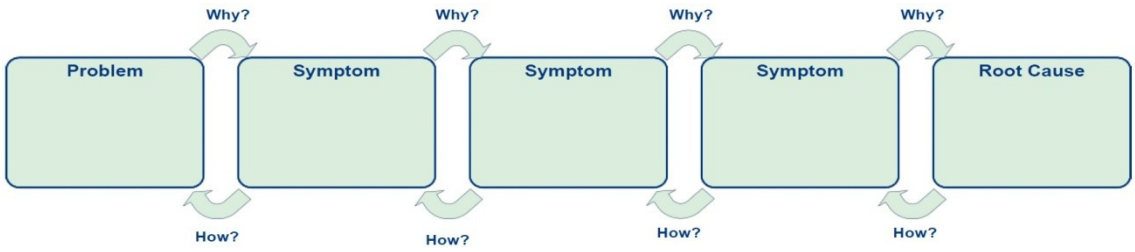



**Figure 5.3 :** The Five Why's Template

**Just in Time (JIT) :**Demand is the base factor of continuos- flow in lean construction and JIT guarantees reducing waiting and reponse times between work flow (Ogunbiyi, 2014).

**Plan of Conditions and Work Environment in the Construction Industry :** This is a lean constructiontool that guarantees occupation safety and health management. It oversees security necessities through the risk management cycle comprising of nonstop identification of risk, evaluation, and control (Ogunbiyi, 2014).

**Concurrent Engineering:**This is an improved design process characterized by rigorous upfront requirements analysis, incorporating the constraints of subsequent phases into the conceptual phase, and tightening of change control towards the end of the design process (Ballard and Howell, 2003; Koskela, 1992).

**Pull 'kanban' system :**The Productivity Press Development Team (2002) stated that the Japanese word "Kanban" means 'card' or 'sign' and is the name given to the inventory control card used in a pull system(Arbulu, Ballard and Harper, 2003). As shown in Figure 5.4, a task process is divided its work flow to progress step by step by completing each sequence.

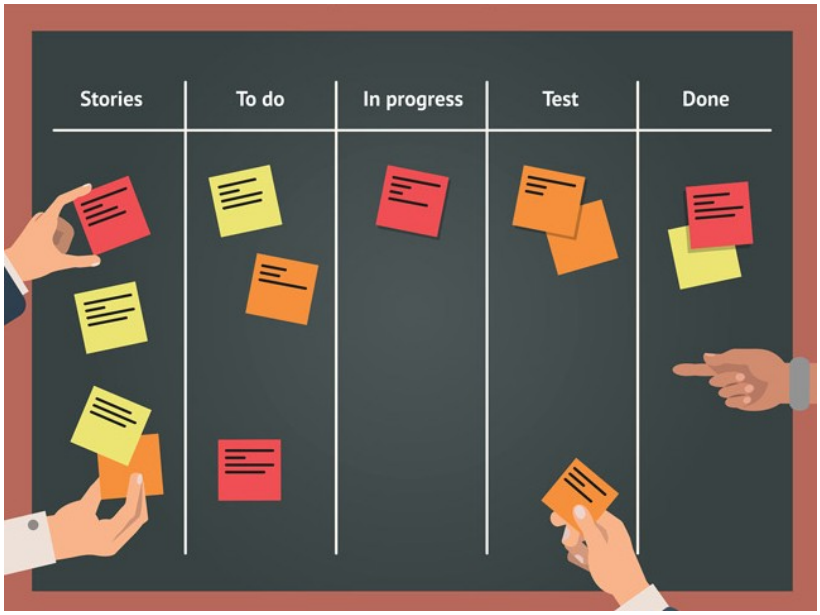



**Figure 5.4 :** Pull (Kanban) System

**Error Proofing (Pokayoke) :**Poka-yoke is a Japanese word which can be defined as "errorproofing" (Conner, 2009).Figure 5.5 explain Poke-Yoke' objectives, this method prevents possible mistakes that could be transform a defect in project (Conner, 2009).

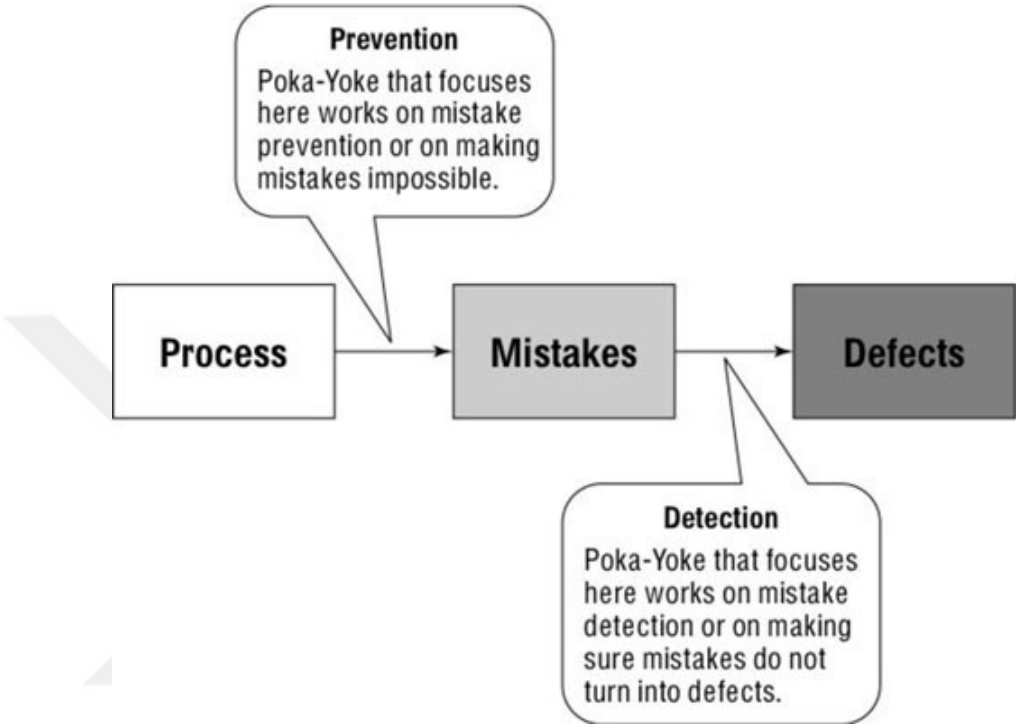



**Figure 5.5 :** Poka-Yoke System

**Target value design (TVD) :**TVD considers the customers'/ clients' and stakeholders' vision to develop in  This approach applies methods for the design to be developed incompliance with the constraints, especially cost.(Miron, Kaushik and Koskela, 2015)

**Partnering :** A potential radical change in management decision needs to be leaded with collaborative organisational structures that must open exchange of information between teams(Barlow, 1996).

**Total Productive maintenance (TPM) :**TPM focuses on operational time  of equipment to provide proactive and preventative maintenance and encourages operators to help maintain their equipment (Al-Aomar, 2012).

**Computer Aided Design (CAD) :**CAD based project management creates models, tests construction feasibility, simulates constrcution process and try operational process of project. This tool helps coordination of project resources directly and macinery, equipments and site team can be managed easily in construction site (Khanzode, Fischer and Reed, 2005).

**Six Sigma :**Six Sigma methodology shown in Figure 5.6 is a staticstical method that provides definition of process, measure of outcomes, analysis of defects, improvement methods and control mechanism to make reduction in the customer defined defect rates(Linderman et al., 2003).

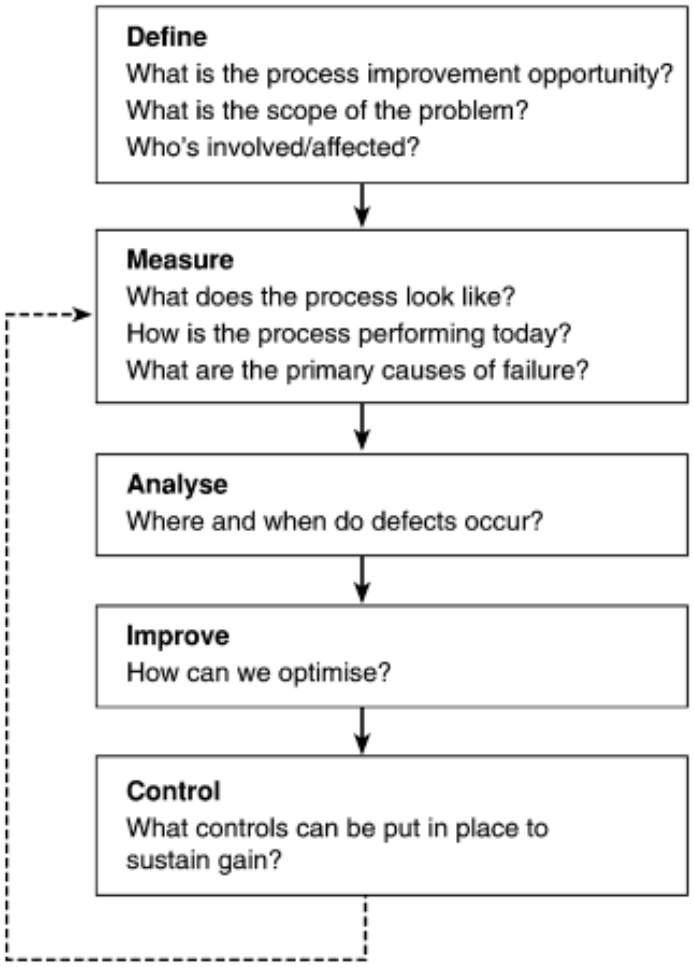



**Figure 5.6 :** Six-sigma's structured methodology – DMAIC (adopted from Brue, 2002)

### 5.2 BIM : As A Tool For Implementation Of LCM

Due to the development of technology and competitiveness in the construction sector,a new era in waste management emerged in the recent period, because interaction between sectors has increased and access to information has become easier. The BIM concept that emerged with the developing technology and Lean Production Principles that prove its success in the automotive sector, are the becoming the new waste management tools of construction industry.

The waste can be reduced by integrating the BIM and lean concepts, where visual monitoring and control can be improved on the site with the BIM, as the whole layout of the site will be available for the project team to be viewed in order to determine the area for storage and the material transportation on site, additionally a visualized detailed schedule of the material handling system is given to the project team. Whereas, employing lean concepts minimizes the storage space and double handling, furthermore instead of using the Push concept, it uses the Pull concept that assists in using the buffer properly while helping with material delivery system.

BIM contributes to control all of the interventions, conflicts and collisions with visual technology for reducing conflicts. This capability allows BIM to act as a consultant for designers and engineers. Models can be meticulously analyzed, simulations can be performed quickly, and performance can be compared, so that project can be completed with minimal changes in a reasonable time and estimated budget.

The BIM is a 3D model through which element dimensions can be properly calculated with better visualization, additionally it is vastly used for shop drawing and is a solution to the issue created due to inaccurate dimensions. The BIM also schedules and manages the prefabrication elements efficiently. BIM can be used as an effective schedule software for ordering construction material, fabrication process and transformation of all components. Clear construction scheduling with BIM reduces the potential damage by ensuring timely delivery of materials and equipment.

The possible problems are noticed and solved in the early stages of design, and there will be less disputes and fewer problems in the progress of construction. All design changes of model are automatically updated, so there will be no errors or omissions

due to correction. During the construction project, the change order has been a great concern, and the construction waste due to change orders constituted for 33% of the total. Lack of communication led to rivalries among various disciplines during the project (Architects, Engineers and the MEP). The amount of change orders were reduced once BIM was implemented in the construction project. Williams claimed that 47% of the waste caused by the change orders in the MEP was reduced by the employment of the BIM design (Williams, 2011).

If 3D design model and construction model are linked correctly, BIM model shows how the building and the construction site would be seen at the any planned time. The procurement and planning problems can be ceased with the help of the latest construction software through their fresh Project management skills. Real time and state of art Project environment and conditions can be examined through the BIM and Location-Based-Management creating a model of the entire construction site, furthermore technical and visual features are available to draw and construct all the components of construction into a real 3D Project model. These models and location based systems simulate the real construction, thus waste of material and time can be avoided when generating just-in-time procurement schedule by simulating each step in the Project. This kind of BIM model is known as 4D BIM which provides ability to reduce the number of additional handling, unnecessary moving and the loss of material lost.

Another area of concern for waste production in the construction industry is double material handling and inappropriate materials, however, several studies were conducted to resolve the issue of double material handling ( Lu and Yuan, 2010).

In addition, BIM model provides exact quantity take-off for building components and thanks to this technology, project managers can take an accurate cost estimation and order correct amount of material.BIM works with ‘Five Big Ideas’ of Lean Thinking to make minimum waste in production line to satisfy maximum customer expectation.

### 5.2.1 Main benefits of BIM for waste assessment findings

Waste assesment findings reveal that sources of the waste causes can be defined at 5 headings as;

1. Planning and programming of project process,
2. Project design and drawing defects,
3. Coordination between design and construction,
4. Communication and collaboration between stakeholders,
5. Construction planning and coordination.

Benefits of BIM implementation are explained againts these 5 source of waste causes.

#### 5.2.1.1 Bim benefits for planning and programming of project process

Project schedules are represented by using Gantt chart. Thorough information of the project is needed to be able to evaluate whether the schedule is possible as it is a representation without clear visualization. Visualization of the sequential construction phases is allowed by BIM as it enables schedulers to create 4D models linked to 3D geometry. Because of this, activities can be visually planned in context of space and time and other project team members can be communicated with, through 4D schedule simulations, by schedulers. BIM tools for project scheduling also make possible resource utilization attribution. Improved communication between team-members and stakeholders and the enhancement of site logistics, through which incentives are provided for a better project coordination and to avoid bottlenecks, are the key advantages (Kymmell, 2008).

The BIM can be used in a multiple of ways depending on the level of maturity of the project. With electronic data exchange, the BIM is used in 2D as unmanaged CAD.
It can be modeled to function as 2D and 3D formats with managed CAD which assists in interlocking data information for a uniform system through all phases of construction. In this case finance strategies and cost management packages are used to control commercial data.

As shown in Figure 5.7, the BIM tools along with the provided data create a controlled 3D environment. This is achieved by utilizing enterprise resource planning

software which is brought together by a dominant middleware for managing commercial data. It is likely that this level uses 4D construction sequencing and/or 5D cost information.At its paramount, the BIM encompasses every aspect of construction that includes web services. This level of the BIM meets the IFC standards (Industry Foundation Class). At this point, the BIM facilitates with 4D construction sequencing, 5D cost information and 6D project life cycle management information.

The BIM is the unconventional solution to construction problems. If used in a suitable manner, the BIM ensures timely completions of the project and is capable of making remarkable positive impacts on the project (Eastman et al. 2008). Azhar's research work of BIM (2008), and CRC (Construction Innovation, 2008) mentioned about the following benefits:

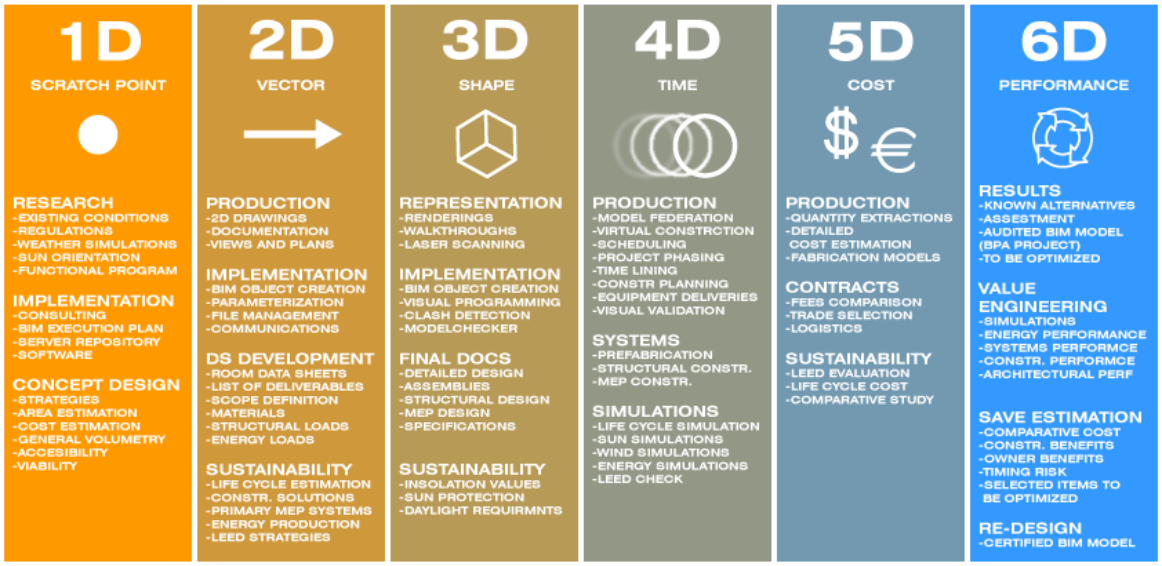



**Figure 5.7 :** Dimensions of BIM

**A well-organized System**: since information is through and readily available.

**Coherent design**: The BIM opens pathways for designers and managers to collaboratively choose the most efficient design in terms of profitability and time management.

**Pre-planning for the entire life cycle of the building**: It takes into account the principles of design and creates achievable milestones for the project.

**Refined quality productions**: resilience in documentation and employment of technology.

**Mechanized assembly**: manufacturing in building industry is achieving new benchmarks.

**Improved customer relations**: the customer has a realization of their ideas with the help of imaging data.

**Effective Facility Management**: The BIM serves as a reserve for information of construction and design implementation and facility managers have an ease of access to the data relieving them from the trouble of recollection of data.

The parties influenced most by any project are the owners and the project managers. They are the decision making bodies overall and decide whether or not to employ the BIM. The BIM is being embraced far and wide for the facilities it imparts to all the parties involved and is rapidly gaining popularity. The BIM is proven fruitful to the owners and withstood the test of time with diminished operational costs and organized data handling.

**Better assesment of project design and option analysis :** The BIM is capable of presenting the decision bodies with options for them to decide the one that suits their requirements best. These options can cater to time, materials and costs etc.
The requirements of a project undergo several changes throughout the execution period. The options of possibilities are usually presented in the form of diagrams or representations provided by the design team. Going through every attribute is an exhaustive process.
Since the BIM is an integrated program, its visual simulations are expansive and help communicate relevant information to all the stakeholders while adjusting to fluctuations in the project requirements effortlessly. The feasibility reports are far sighted. This is another detrimental factor for effective decision making (Azhar et al, 2012).

**Increased collboration and mitigating litigations :** When it comes to contractual conduct and accountability, the BIM abides by the law requirements. The BIM is thorough in transferring responsibilities and in acquiring due accountability from the

team which is required to perform a specific task. This improves collaboration between teams and requires teams to co-operate with each other for a smooth running project (Conover et al., 2009).

**Estimation of budget :** Cost overrun is an expected and unavoidable complication which running projects encounter according to the study of FMI/CMAA (2005; 2006). According to this study 2/3 of projects suffer from cost overrun. Eastman et al state that reliable cost estimation makes the BIM a lean process and profitable system especially in the beginning of the project when materials are purchased.

**Control costs during project lifecycle :** Feasibility of a project is detrimental in its effectiveness and creating cost reliability. The manner in which the BIM influences the cost reliability is a positive driving force towards adoption of this system. It benefits the project by predicting estimations that are more reliable along with the information that pertains to it. Secondly, the cost estimation can be done sooner which helps the owner take better decisions in the future. However, the BIM does not make provisions for sudden unexpected changes in cost and unskilled cost accountants who have little knowledge of managing costs. (Conover, et al., 2009)

**Increased data coordination :** The passing down of stages in the project execution creates loss of data in the subsequent stages and creates delays and reworks for assuming that data again. This increases cost for the owner and loss of data integrity.
In traditional models, the data collected is sometimes irrelevant. A study made in the USA by NIST and Fiatech (2006), shows that capital facility industry suffers because of this. This study shows a net loss of $16 billion in 2002 due to inoperability since the data inherited was of no use. 2/3 of this loss was suffered by the owners. The BIM shares linked statistical data which everyone can benefit from consistently. Eastman et al (2011) gave an elaborate representation of data loss which led to provisions to avoid it all together in the BIM adding value to data.

**Reduced time to market :** The dangers linked with the market fluctuations can be decreased and the profitability can be increased by gaining revenues from a facility faster because of the reduction in the time taken to finalize and bringing a construction project to the market.

The time to market of a facility can be reduced in many ways by BIM technology. Firstly, the design process can be automated partly and the duration of design changes can be decreased through the utilization of parametric modeling. The second is that productivity can be increased and project durations can be decreased with prefabrication and design elements can be rapidly explored to prefabrication sites and this process can be coordinated using BIM. Thirdly, 4D model capabilities, like time scheduling tools through which better monitoring of activities and better planning capabilities are provided, are present in BIM.

**A tool for facility management :** When exploiting a project, a building model can also perform the role of a facility asset management tool. The condition of the facility can be looked upon, maintenance can be managed and planned or the effects of retrofit work can be assessed, by the owner (Eastman, et al., 2011).
It has been assumed that the service providers who establish the models are assuring them sufficient scope, level of detail and providing the required information for the aforementioned enumerated uses of building models.

#### 5.2.1.2 Bim benefits for design and drawing of project

**Design alternatives to select most suitable design :** Visual Design and Construction models were described by Kunz & Fischer (2011) as the utilization of integrated multi-disciplinary performance models of design construction projects to support specific and public business purposes. According to the Center for Integrated Facility Engineering (CIFE) the flow of information among the stakeholders of a project can be modeled and represented via computer in the form of symbolic representations of Products, Organizations, and Processes (P-O-P) (Khanzode et al., 2006).

Increased collaboration required for decision-making, more effort in developing the set of construction documents and assembling the information and the investment required to change the work method to BIM are included in these costs. The additional costs should be justified by the following paragraphs as they present some of the advantages given to the design process by BIM.

More of the design effort is required when conducting the initial parts of a project by the BIM process of design. During this, the design can be altered with less cost. Graphical representation will be the most suitable for this situation.

**Clash detection and analysis tool :** Feasibility for the design is ensured by BIM technology as it enables inconsistencies in the design check to be checked by clash detection software. There is much significance of these features in the adoption of BIM due to their direct costs reduction capabilities and these features also add value directly to the quality of the design process.

The time taken to perform analysis for structural, energy, safety or simulation tools will be reduced because of the possibility to use the model for analyzing these. When the construction of the model is according to the requirements of the analysis tool, both as geometry and as exchange format, this feature is increasingly advantageous. Precise bills of quantity output, costs estimations tools and scheduling applications are supported using the building model. These tools can assist in tuning the design to fit the designated construction costs instead of estimating and amputating it at the end, therefore, they are really beneficial for the design process.

**Automatic and consistent drawings :** BIM represents each object instance not more than once. The shape of objects, the properties and its location within the model are included in this. Extraction of all drawings, reports and datasets is possible in a non-redundant and thus consistent mode because of this feature.

A significant cause of errors typical to 2D drawing designing where new drawing, which sometimes are not consistent with the old versions because of human errors or omissions, are used to represent the changes and edits, is solved by this property of building models itself.

There is a decrease in the cost of drafting each 2D drawing individually and the possibility of inconsistencies concerning it as outputting automated drawings of different 2D or 3D views from the model is allowed by BIM. Furthermore, direct fabrication drawings can be exported to fabricators and installers through specific BIM software (Leicht, et al., 2011).

**Synchronization allowing for unique model :** Becoming locations for storing, exchanging and updating, with project synchronization, the models is the objective of BIM servers. Due to project synchronization meaning that all the project files worked on from various users are brought together consistent with one another for constituting a non-redundant model, there is great significance of it for BIM.

Complete automation of the synchronization has not yet been done at this development point for BIM technology because of the design decisions necessary for making revisions for consistency. Henceforth, a part of the synchronization process is still represented by human management and fully automatic synchronization is not possible currently. For individual identification, timestamps (information regarding by whom and when was the object last updated) and global unique IDs (GUIDS) are carried by the objects. Metadata is the term used to refer to this information and it assists to achieve the automatization of synchronization and clash detection and manage the changes done to objects in time (Leicht, et al., 2011).

**Forwarding know-how :** Software firms, which produce the BIM software, and other concerned software firms, which work collectively alongside industry groups and experts for expanding the library of object classes, develop the parametric object. Users can develop their own object class and personalize the software according to their requirements through some BIM software. Firms which frequently perform the same type of specialized work and which desire to introduce their earned work experience into their parametric design capacity can make great use of this. Therefore, knowledge can be embedded and fine-tuned on time according to past efforts on design, production, assembly and maintenance based on what works and what doesn't, by the companies.

**Evaluation for energy consumption and sustainability :** As per the perspective of the facility management, the significance of sustainability and energy consumption for buildings is elevating. A large portion of a facility's costs is represented by operational costs throughout its lifecycle and it can be maximum 80%. Energy use of a building can be assessed by many BIM tools. At the time of selecting design substitutes which enhance energy consumption and maximize energy utilization, great advantages are provided by this (Conover, et al., 2009).

#### 5.2.1.3 Bim benefits for coordination between design and construction

During the construction project, the change order has been a great concern, and the construction waste due to change orders constituted for 33% of the total. Lack of communication led to rivalries among various disciplines during the project (Architects, engineers and the MEP). The amount of change orders were reduced once BIM was implemented in the construction project. Williams claimed that 47% of the waste caused by the change orders in the MEP was reduced by the employment of the BIM design (Williams, 2011).

Several root causes can be observed for the changing order in this industry. One root cause is that the client is unable to clearly express his vision from the starting of the project, to solve the issue there's the architect who should completely visualize the picture demanded by the client, and take assistance from the visualizations software to derive the client's idea efficiently. Another root cause is very common, particularly if the designer is unacquainted with the construction market that when the construction material is not available in the market, the solution to this problem exists in the DB contract or appointing a construction manager for the design phase of the project. If the design stakeholders and the execution team are not on the same ground due to communication and collaboration issues, disputes will arise either in the form of clashes or some specifications remained unfulfilled at present due to a restriction in the project.

**Integration of design and construction processes :** Both benefit from the better integration of the design and construction processes. Earlier involvement of the contractor and its subcontractors and fabricators in the project when the BIM model is constituted is the basis for it. They are able to transfer more of their knowledge to the project earlier when design changes are more simplistic because of this. As this allows the complete integration of modifications into design, the procurement period is shortened and the value of the design is elevated. In addition, coordination errors at the time of construction are reduced through review and project tracking based on the model, the fabrication detailing is fastened, inconsistencies from fabrication manufactories are avoided, identification of construction limitations is facilitated and insight is allowed from the contractor and fabricators for increasing constructability and reflecting best practices, because of it. The best utilization of BIM is as a

collaborative tool at the initial stages as it was implied by IPD (Integrated Project Delivery) that the designer, architect and main contractor work collectively from the starting of a project in a joint contract.

**Avoid design errors with clash detection :** Design errors can be precisely identified using automatic clash detection tools, without which a prone to error manual process would have to be used. When sufficient access, safety measures, insulation or maintenance for example is not present for objects, “hard clashes” can be identified with clash detection. The BIM user has to insert component classification and conditions and thus develop a detailed and well defined building model so that soft clashes could be identified by a clash tool. For this, the team members have to further collaborate so that design errors could me found and managed and the information that relates to their responsibilities could be introduced.

**Cost estimation tools :** Interim cost estimations are facilitated by BIM tools for quantity takeoffs and cost estimating. The laborious task of quantity take-offs and up to date cost estimations are facilitated and that is the advantage. Time required for the generation of cost estimates is reduced by 80% through BIM, as per the Stanford University Center for Integrated Facilities Engineering (CIFE) having statistic result from 32 projects using BIM (Gilligan and Kunz, 2007). Through this, problems can be found sooner and alternative solutions can be considered when changes could be made for meeting the cost restrains.

**Offsite fabrication use :** Labor costs and onsite installation risks are typically reduced by offsite fabrication. Having details regarding geometry, materials specifications, finishing requirements and delivery sequence, the contractors can communicate BIM component details directly to fabricators through BIM tools. Because of the precise BIM information, the reduced times related to verification and validation of the orders results in the advantages (Kymmell, 2008).

Direct benefits have been suggested by results from an analysis conducted by the Stanford University on the basis of 32 important projects using BIM. The advantages are up to 7% reduction in project time, savings up to 10% of the contract value through clash detection, up to 80% decrease in time required for the generation of a

cost estimate, cost estimation accuracy within 3% and up to 40% elimination of unbudgeted costs (Gilligan and Kunz, 2007).

In conclusion, providing a "file to factory" parts fabrication system, allowing connection to analysis and simulation software, enhancing cooperation between partners, achieving higher accuracy and flexibility, avoiding design mistakes, accelerating construction and increasing design speed are the foremost benefits of BIM (Welman and Bonjour, 2012).

#### 5.2.1.4 Bim benefits forcommunication and collaboration

Poor communication is found in several levels during the project, firstly when the stakeholders communicate poorly, which was quite commonly found in several construction projects and is the most existent communication problem. But when moving ahead, a poor communication and passive participation amongst project stakeholders have aggravated the issue of project waste management.

BIM technology has made it easier by creating a link between stakeholders and project representatives to work together for creating an effective and competent designs and proficient execution of projects. With the use of such advanced technology, the end results are also worth the wait. Innovative design and development of a project results in an increase in the value for internal and external users of that resource, valuable construction techniques and considerable decrease in waste.

In order to facilitate the optimized use of BIM, it is important to share the data among team members at various life cycle stages of a facility. At this point, the issue of interoperability arises as the lack of interoperability affects the BIM process workflow, which influences the project's budget (Young Jr. et al., 2007). In 2007, McGraw-Hill stated that by manually re-entering data from application to application was the prime cost associated with interoperability because by re-entering data from BIM into another application results in unproductive and costly duplication of effort. Other costs include more time spent in processing requests for information, time used up using duplicate software and time wasted to document version checking. Therefore, the lack of interoperability hinders that exchange which leads to

unnecessary work and extra time invested and money spent in substandard solutions that raise project costs (Young Jr. et al., 2009).

In 2011, The Institute for BIM in Canada agreed to the fact that with BIM adoption there has been a considerable decrease in various types of paper documents. They further stated that for an efficient utilization of BIM, the quality of communication between stakeholders is very important. Usually all objects with their attributes are exported from the designer models by the design team, which results in a massive amount of data collection.

Overloading of data could be overwhelming and at times useless (Jellings, 2012). The data standards are very essential for the development of key performance indicators (KPI) and creating a scale. To avoid the complexity of data it is vital to stick to the standard so that it simplifies the process. According to The National Institute of Building Sciences (2007), the sending party needs to add information and create a model before the receiving party checks it. For smoother flow of information, the team should agree on the type of information and the time when it will be included in the model. Each party can plan its work accordingly, as to which information should be provided and at what time period and what to be expected through the model. This process planning is beneficial in avoiding duplication, enabling efficiencies, and gaining advantages from BIM adoption.

#### 5.2.1.5 Bim benefits for construction planning

**Procurement and work scheduling :**Procurement is associated with managing the materials for construction, which may badly affect the cost and schedule of the Project, in case the managers improperly arranged the quantities documented and work activities scheduled. Depending on the construction technique, the outgoings flow is determined by the procurement sequences of material. The amount of waste is determined by the sequence of tasks and calculation of productivity from the starting of the Project, even though the managers add margins for quantities of materials and delay time for delivery of resources. The manager can predict the waste in each step by giving a proactive plan list of the Project.

The procurement and planning problem that was a concern can be ceased with the help of the latest construction software through their fresh Project management skills. Real time and state of art Project environment and conditions can be examined through the BIM and Location-Based-Management creating a model of the entire construction site, furthermore technical and visual features are available to draw and construct all the components of construction into a real 3D Project model. These models and location based systems simulate the real construction, thus waste of material and time can be avoided when generating just-in-time procurement schedule by simulating each step in the Project.

**Inadequate construction waste management :** Thatconsists of inadequate tracking of movement of construction waste, improper planning of space for construction waste, improper planning for storage of material, and late on-site waste sorting. Implementation of the BIM or any other theory won't be of any assistance here unless a culture for tracking of waste is developed during the project from the project managers till the lowest level of the project hierarchy.

## 5.3 A Proposed Waste Management Approach For Turkish Construction Industry

As a result of interviews and surveys, 29 main waste causes have been identfied for Turkish construction industry in relation with their frequency of occurrences. Each waste cause reduced by using one of the lean tools. Table 5.1 presents Lean Tools against each waste type. Waste causes can be encountered at 7 work phases as;

1. Planning and programming of the project
2. Project design
3. Project drawing
4. Project coordination
5. Project contructor selection
6. Begining of construction
7. Execution of construction phases.

The solutions to wastes at 7 phases will provide minimazing of construction wastes in Turkish Construction Industry.

**Table 5.1:** Use of Lean Tools Against Main Waste Causes

| No | Possible Lean Tools For Waste Causes | | Main Waste Causes | Average Value |
|---|---|---|---|---|
| 1 | The Last Planner System (LPS) | Just in Time (JIT) | Inefficient planning and programming of the project | 4,4 |
| 2 | Computer Aided Design (CAD) | Target Value Design (TVD) | Frequent revisions to drawings or designs cause additional work or rework | 4,2 |
| 3 | Computer Aided Design (CAD) | Concurrent Engineering | Inadequate and faulty project coordination | 4,2 |
| 4 | The Last Planner System (LPS) | Value Stream Mapping (VSM) | Inadequate payments or no payment | 4,2 |
| 5 | Computer Aided Design (CAD) | Daily Huddle Meetings | Project faults | 4,2 |
| 6 | Computer Aided Design (CAD) | Concurrent Engineering | Construction difficulty due to design | 4 |
| 7 | Value Stream Mapping (VSM) | Just in Time (JIT) | Disputes that cause client / consultants to stop work | 4 |
| 8 | Computer Aided Design (CAD) | Concurrent Engineering | Frequent revisions in drawings or design | 4 |
| 9 | Concurrent Engineering | The Five Why's | Incorrect selection of construction method | 4 |
| 10 | Computer Aided Design (CAD) | Standardized Work | Repetition of work due to design changes and revisions | 4 |
| 11 | The Last Planner System (LPS) | First run studies | Unrealistic work plan | 4 |
| 12 | Daily Huddle Meetings | Increased visualization | Construction faults made by site teams | 4 |
| 13 | Partnering | Increased visualization | Communication problem between teams and supervisor | 3,8 |
| 14 | Kaizen | Pull system | Delay of material supply | 3,8 |
| 15 | Concurrent Engineering | Daily Huddle Meetings | Insufficient level of supervision | 3,8 |
| 16 | The Last Planner System (LPS) | Value Stream Mapping (VSM) | Irregular cash flow | 3,8 |
| 17 | First run studies | Increased visualization | Lack of craftmen quality | 3,8 |
| 18 | First run studies | Increased visualization | Lack of experience of teams | 3,8 |
| 19 | The Last Planner System (LPS) | Value Stream Mapping (VSM) | Lack of money incentive | 3,8 |
| 20 | The Last Planner System (LPS) | Concurrent Engineering | Lack of weekly project evaluation meetings | 3,8 |
| 21 | The Last Planner System (LPS) | Concurrent Engineering | No periodic meetings between management, contractors and site staff | 3,8 |
| 22 | Just in Time (JIT) | First run studies | The slow progress of the decision-making process | 3,8 |
| 23 | Computer Aided Design (CAD) | Total Quality Management | Inadequate instructions provided by the supervisor | 3,6 |
| 24 | Computer Aided Design (CAD) | Pull system | Material requirement program not being performed properly | 3,6 |
| 25 | Pull system | Computer Aided Design (CAD) | Material stock made without paying attention to the work schedule | 3,6 |
| 26 | Total Quality Management | Target Value Design (TVD) | No periodic meetings between management, contractors and site staff | 3,6 |
| 27 | Computer Aided Design (CAD) | Daily Huddle Meetings | Process slowdown due to differences in drawings | 3,6 |
| 28 | Just in Time (JIT) | Total Quality Management | Slow progress of the maintenance process in case of failure | 3,6 |
| 29 | Pull system | Computer Aided Design (CAD) | Waiting for replacing materials that do not meet the project requirements specified in the design files | 3,6 |

Figure 5.8 shows a proposed Lean & BIM Based Waste Management Approach. In the approach, there are two kinds of tools; coordination tools and control tools.

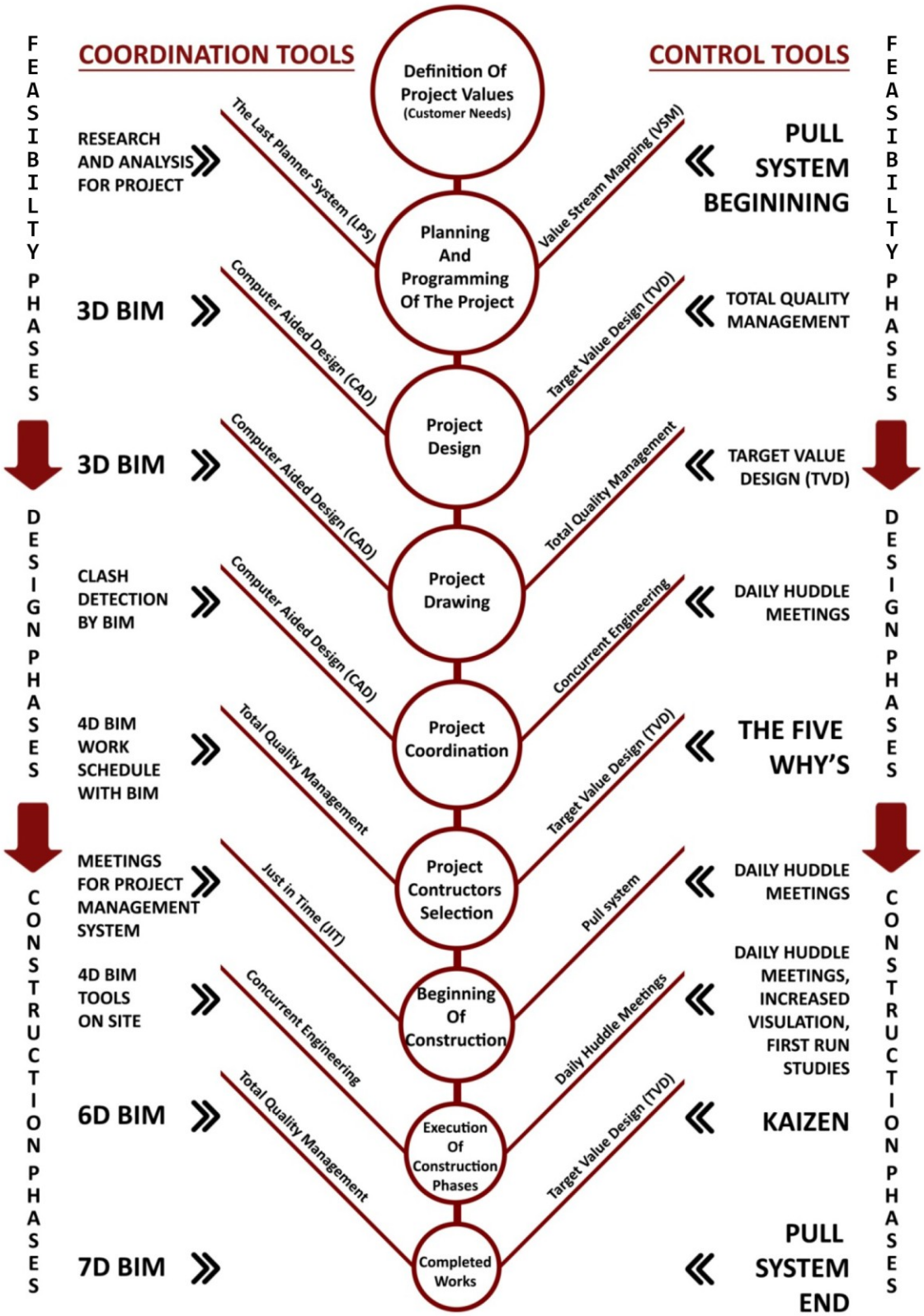



**Figure 5.8 :** Lean & BIM Based Waste Management Approach

BIM is defined as a coordination tool in a project and the level of BIM should be developed according to implementation phase. On the other hand Lean Construction Methods are defined as main control tools including pull system, total quality management, target value design, daily huddle meetings, The Five Why's, increased visulation, first run studies and Kaizen from beginning to end of the project. Main control tools provide quantity and quality determination between stakeholders.In addition, submission tools for each stakeholders are identified for providing coordination and control between related stakeholderof executed work.

As a waste cause in Turkish Construction Industry, Inefficient Planning and Programming of Project has the highest average value of 4.4 amount. The Last Planner System should use to define detailed work flow in master schedule and possible problem in master schedule must be identified by project stakeholders before begining of the project. Possible problem causes must be evaluated with Value Stream Mapping and different optional work flows should be design for crises in project process. Value Stream Mapping must be implemented until completion of construction.

Project faults, frequent revisions in design and drawings, design cause additional work or rework, construction diffuculty due to design are project based waste causes in construction, for this reason Project Design, Project Drawing and Project Coordination defined as phases to solve waste causes bacuse of design and construction projects. To reduce waste causes, BIM should use by each project design teams to provide full-coordination and Target Value Design teqnique should be implemented to apply project values. In addition, Total Quality Management is not a tool only used in construction execution phase, but also it should use in project process with the idea of plan-do-act for preventing construction diffuculty due to design.

Lack of coordination between project and consruction teams causes important wastes during the construction. The Five Why's of Lean Principles, coordination and control tools should be explained to selected contructor(s) before beginning of construction. Contructors should make their master construction work sechedule, material and equipment requirement programs, material stock organization, qualified craftmen

and team member organizaion, cash flow schedule by using BIM to provide coordination. In addition, implemantation of Just In Time and Concurrent Engineering with daily meetings will prevent delay of work steps. BIM and pull system must be implemented from begining to end of project phases.

In Turkish Construction Industry, the major problems occurs because of the lack of coordination and communication. The effective use of BIM between stakeholders and use pull system with daily huddle meetings helps implementation of master schedule and identification of possible problem before it happens. For coordination of site teams and preventing lack of qualified manpower, increased visulation and first run studies are effective tools to reduce waste in construction execution.

# 6. CONCLUSION AND SUGGESTIONS

The construction industry plays a vital role in improving the economy as its one of the largest contributors of massive scale projects in the market. It includes highly specialized processes and representatives who are working as a team to achieve high quality, profitable facilities and structural resources on time. However, inappropriate planning of projects from the beginning to the end causes many problems such as delays, waste, cost, quality etc. There some tools and techniques that can be used to solve problems encountered and to improve the satisfaction of the project.

Lean production system and Building Information Model (BIM) are two of these tools and techniques. Lean Production System is used to eliminate construction wastes, improve working conditions and maximize customer expectations. BIM provides a visual control and monitoring approach so that all sort of conflicts can be reduced.

In this study, causes of waste and their effects to construction industry are analyzed and Lean and BIM based waste management approach is proposed to minimize the effects of waste causes. Interviews are carried out with five Construction Firms in order to know what sort of waste causes occurs in Turkish Construction Industry. Questions for interviews are prepared in the frame of Taiichi Ohno's waste approach. Respondents asked to answer the questions regarding their experience. Results of the interviews show that main waste cause is "inefficient planning and programming" which leads to the lack of project delivery and organization skills in construction. Waste causes occur mainly at design, operation and procurement stages of a project.

Waste causes can be prevented by using one of Lean and BIM tools such as Last Planner System, Computer Aided Design, Value Stream Mapping, Partnering and so on. In this study, as a proposal, each waste cause is matched with one of these tools so that waste cause can be perevented to enhance the satisfaction of the project for all parties involved.

Proposed Integrated Lean Principles and BIM Based Waste Management Approach provides two kinds of tools as coordination and control whic can be served at feasibilit, desigmn and construction phases. In addition while coordination tool enable the use BIM, control tool is for the use of Lean Principles.

Waste Management Approach proposed in the study can be a useful to reduce wastes in Turkish Construction Industry. Lean Principles should be chosen according to unique conditions of project and stakeholders in early stages of project to increase efficinecy of project resources. For BIM, qulified workers must be employed for each stakeholder to provide full-communication and coordination between projects and teams. The use of Lean Construction Methods, as an waste management model can be helpful and BIM can be used as a tool for implementing that model properly to minimize wastes in Turkish Construction Industry,

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APPENDICES

**Appendix A:** Yalın İnşaat Uygulamalarında İsrafların Tespiti Anket Çalışması

## APPENDIX A

### YALIN İNŞAAT UYGULAMALARINDA İSRAFLARIN TESPİTİ

**( Soru ve Cevaplar akademik araştırma amaçlıdır.)**

Bu araştırma, Mimar Sinan Güzel Sanatlar Üniversitesi Fen Bilimleri Enstitüsü Yapı Mühendisliği Anabilim Dalı Yapım ve Proje Yönetimi Yüksek Lisans Programı dahilinde, yürütülmekte olan "Yapı Bilgi Modelleme Tabanlı Yalın Proje Yönetimi" konulu yüksek lisans tezi için yapılmaktadır. Kimlik bilgileriniz ile verdiğiniz bilgilerin hiçbir surette başka bir amaçla kullanılmayacağı ve 3. şahıslara verilmeyeceği teminatımız altındadır. Sizden ricamız anket sorularını eksiksiz ve görüşlerinize uygun olarak doldurup, anket sonundaki sorulara size en uygun cevapları vermenizdir. Katkılarınız için teşekkür ederiz.

**Gökhan DEDE** — **Prof. Dr. Sema ERGÖNÜL**

Yüksek Lisans Öğrencisi — Tez Yöneticisi

**(Lütfen boşlukları doldurunuz ya da (X) koyarak işaretleyiniz.)**

1. **Proje türü :**
   .....
2. **Proje yeri :**
   .....
3. **Cevaplayan kişinin adı-soyadı (İsteğe bağlı) :**
   .....
4. **Cevaplayan kişinin mesleği ( Ünvanı ) :**
   .....
5. **İnşaat sektöründe deneyim süresi :**
   .....
6. **İşveren türü:**

- ( ) Müsteri ( ) Ana-Yüklenici ( ) Alt-Yüklenici ( ) Danışman
- ( ) Proje Müellifi ( ) Üçüncü Şahıs Kurumlar

7. **İnşaat proje yönetiminin hangi kapsamlarında aktif rol aldınız ?**

- ( ) Tasarım ( ) Risk Yönetimi ( ) Sözleşme Yönetimi & Doküman Yönetimi
- ( ) Süreç Yönetimi ( ) Maliyet Yönetimi ( ) Kalite Yönetimi

8. **Yalın inşaat uygulamaları hakkında bilgi sahibi misiniz?**

   ( ) Evet ( ) Hayır

9. **Yapı bilgi modellemesi hakkında bilgi sahibi misiniz?**

( ) Evet ( ) Hayır

**Anket soruları ile inşaat sektöründeki israf sebeplerinin belirlenmesi ve derecelendirilmesi amaçlanmıştır.**

Yalın İnşaat Teknikleri kapsamında inşaat endüstrisinde gecikmelere ve maddi kayıplara sebep olan israf kaynakları 7 başlık altında ele alınmıştır.

| No | İSRAF KAYNAKLARI | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Malzeme ve Ekipmanın Gereksiz Nakliyatı | | | | | |
| 2 | Depolama ve Stok | | | | | |
| 3 | İş Gücünün Gereksiz Yer Değişikliği | | | | | |
| 4 | Gecikmeler | | | | | |
| 5 | Fazla İşlem | | | | | |
| 6 | Fazla Üretim | | | | | |
| 7 | Ürün/Süreç hataları | | | | | |

Her başlık altındaki israf sebebi maddelerinin inşaat sektöründeki etkisinin belirlenmesi için deneyiminize bağlı olarak aşağıda belirtilen israf sebeplerine katılma düzeyinizi **( 1 = Etkili Değil, 2 = Kararsızım, 3 = Az Etkili, 4 = Etkili, 5 = Kesinlikle Etkili )** 1-5 arasında olacak şekilde seçeneklerden yalnızca bir tanesine (X) koyarak işaretleyiniz. Eğer var ise, diğer israf sebeplerini yazınız.

## 1. MALZEME VE EKİPMANIN GEREKSİZ NAKLİYATI

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Yetersiz nakliye sistemi nedeni ile oluşan taşımalar | | | | | |
| 2 | Malzemenin şantiyede gereksiz yer değiştirmesi | | | | | |
| 3 | Malzeme ocağına giden yolun gereksiz uzunluğu | | | | | |
| 4 | Betonun çok uzak yerden şantiyeye ulaşması | | | | | |
| 5 | Yükleme / Boşaltma / İstif islerinde yaşanan kayıplar | | | | | |
| 6 | Projenin etkisiz planlanması ve programlanması | | | | | |
| 7 | Çalışma sahasında gerekli işgücünün bulunmaması | | | | | |
| 8 | Malzemelerin şantiyeye taşınma esnasında zarar görmesi | | | | | |
| 9 | Malzemelerin şantiyede taşınma esnasında zarar görmesi | | | | | |
| 10 | Tasarımda değişiklik ve revizyonlar sebebiyle işin tekrarlanması | | | | | |

DİĞER: .....

## 2. DEPOLAMA VE STOK

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | İş programına dikkat etmeden yapılan ihzarat | | | | | |
| 2 | Malzemelerin depolanması için yeterli alan olmaması | | | | | |
| 3 | Çalışma sahasında malzeme bulunamaması | | | | | |
| 4 | Malzeme tesliminde gecikme olması | | | | | |
| 5 | Aşırı malzeme alımı ve stoklanması | | | | | |
| 6 | İdarenin onaylamadığı ihzarat in bulundurulması | | | | | |
| 7 | İmalatta kullanılmayacak kalitede malzemenin stokta bulunması | | | | | |
| 8 | Malzeme ihtiyaç programının düzgün yapılmaması | | | | | |
| 9 | İmalatın planlamaya uygun yapılmamasından kaynaklı fazla stok | | | | | |
| 10 | Haftalık proje değerlendirme toplantılarının eksikliği | | | | | |
| 11 | Denetimin yeterli düzeyde yapılmaması | | | | | |
| 12 | Ekiplerin deneyim eksikliği | | | | | |

DİĞER: .....

## 3. İŞ GÜCÜNÜN GEREKSİZ YER DEĞİŞİKLİĞİ

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Gerçekçi olmayan iş planı | | | | | |
| 2 | Çalışanların işyerine ulaşımındaki zaman kayıpları | | | | | |
| 3 | Çalışanların ekipmanlara ulaşımındaki zaman kayıpları | | | | | |
| 4 | Çalışanların ihtiyaçları için harcanan zaman (yemekhane, WC, sigara vb) | | | | | |
| 5 | Alt-yüklenici firmadan kaynaklanan kayıp zaman (işçi ulaştırma, malzeme taşıma vb) | | | | | |
| 6 | Şantiye içi ulaşımda yaşanan zaman kayıpları | | | | | |
| 7 | Yetersiz ve hatalı proje koordinasyonu | | | | | |
| 8 | Şantiye ekipleri arasında iletişim eksikliği | | | | | |
| 9 | Çalışma sahasında gerekli araçların ve ekipmanların bulunmaması | | | | | |
| 10 | Çizimlerde veya tasarımda sıklıkla revizyon yapılması | | | | | |
| 11 | Yapım yönteminin yanlış seçilmiş olması | | | | | |

DİĞER: .....

## 4. GECİKMELER

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Gerçekçi olmayan iş planı | | | | | |
| 2 | Yetersiz ve hatalı proje koordinasyonu | | | | | |
| 3 | Danışmanların / mal sahibinin işi durdurmasına neden olan anlaşmazlıklar | | | | | |
| 4 | Malzeme tedariğinin gecikmesi | | | | | |
| 5 | Şantiye ekipleri arasında iletişim eksikliği | | | | | |
| 6 | Ekipler ve denetçiler arasında iletişim sorunu | | | | | |
| 7 | Karar verme sürecinin yavaş ilerlemesi | | | | | |
| 8 | Yönetim, saha personeli ve yükleniciler arasında periyodik toplantı olmaması | | | | | |
| 9 | Denetimin yeterli düzeyde yapılmaması | | | | | |
| 10 | Danışman tarafından sağlanan yetersiz talimatlar | | | | | |
| 11 | Ekiplerin deneyim eksikliği | | | | | |
| 12 | Ekipler tarafından yapılan imalat hataları | | | | | |
| 13 | Ekiplerin devamsızlığı | | | | | |
| 14 | Ekipman naklinin veya kurulumunun gecikmesi | | | | | |
| 15 | Çizimlerden kaynaklanan farklılık nedeniyle sürecin yavaşlaması | | | | | |
| 16 | Çizimlerde veya tasarımda sıklıkla revizyon yapılması | | | | | |
| 17 | Tasarımdaki imalat zorluğu | | | | | |
| 18 | Arıza durumunda bakın-onarım sürecinin yavaş ilerlemesi | | | | | |
| 19 | Çalışmaya engel olan iş kazaları | | | | | |
| 20 | Çalışmaya engel olan hava koşulları | | | | | |
| 21 | İş grevleri | | | | | |
| 22 | Düzensiz nakit akışı | | | | | |
| 23 | Parasal teşviklerin eksikliği | | | | | |
| 24 | Işçilik kalitesinin eksikliği | | | | | |
| 25 | İşçi önerilerini / fikirlerini göz ardı etme | | | | | |
| 26 | Bürokratik işlemler | | | | | |
| 27 | Tasarım dosyalarında belirtilen proje gereksinimlerini karşılamayan malzemelerin ulaşması ve yenisiyle değişmesinin beklenmesi | | | | | |

DİĞER: .....

## 5. FAZLA İŞLEM

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Gerçekçi olmayan iş planı | | | | | |
| 2 | Haftalık proje değerlendirme toplantılarının eksikliği | | | | | |
| 3 | Yönetim, saha personeli ve yükleniciler arasında periyodik toplantı olmaması | | | | | |
| 4 | Denetimin yeterli düzeyde yapılmaması | | | | | |
| 5 | Danışman tarafından sağlanan yetersiz talimatlar | | | | | |
| 6 | Ekiplerin deneyim eksikliği | | | | | |
| 7 | Çalışmaya engel olan iş kazaları | | | | | |
| 8 | Ekipler içinde ve arasında takım ruhu eksikliği | | | | | |
| 9 | Yapım yönteminin yanlış seçilmiş olması | | | | | |

DİĞER: .....

## 6. FAZLA ÜRETİM

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Gerçekçi olmayan iş planı | | | | | |
| 2 | Yetersiz ve hatalı proje koordinasyonu | | | | | |
| 3 | Malzemelerin depolanması için yeterli alan olmaması | | | | | |
| 4 | Şantiye alanı sıkışıklığı | | | | | |
| 5 | Haftalık proje değerlendirme toplantılarının eksikliği | | | | | |
| 6 | Yönetim, saha personeli ve yükleniciler arasında periyodik toplantı olmaması | | | | | |
| 7 | Denetimin yeterli düzeyde yapılmaması | | | | | |
| 8 | Danışman tarafından sağlanan yetersiz talimatlar | | | | | |
| 9 | Ekiplerin deneyim eksikliği | | | | | |
| 10 | Ekipler içinde ve arasında takım ruhu eksikliği | | | | | |
| 11 | Ekipler tarafından yapılan imalat hataları | | | | | |
| 12 | Yapım yönteminin yanlış seçilmiş olması | | | | | |

DİĞER: .....

## 7. ÜRÜN / SÜREÇ HATALARI

| No | İsraf Sebepleri | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Gerçekçi olmayan iş planı | | | | | |
| 2 | Yetersiz ve hatalı proje koordinasyonu | | | | | |
| 3 | Tasarım dosyalarında belirtilen proje gereksinimlerini karşılamayan malzemelerin ulaşması ve yenisiyle değişmesinin beklenmesi | | | | | |
| 4 | Danışmanların / mal sahibinin işi durdurmasına neden olan anlaşmazlıklar | | | | | |
| 5 | Şantiye ekipleri arasında iletişim eksikliği | | | | | |
| 6 | Ekipler ve denetçiler arasında iletişim sorunu | | | | | |
| 7 | Karar verme sürecinin yavaş ilerlemesi | | | | | |
| 8 | Yönetim, saha personeli ve yükleniciler arasında periyodik toplantı olmaması | | | | | |
| 9 | Denetimin yeterli düzeyde yapılmaması | | | | | |
| 10 | Danışman tarafından sağlanan yetersiz talimatlar | | | | | |
| 11 | Ekiplerin deneyim eksikliği | | | | | |
| 12 | Ekipler tarafından yapılan imalat hataları | | | | | |
| 13 | Ekiplerin devamsızlığı | | | | | |
| 14 | Çalışma sahasında gerekli araçların ve ekipmanların bulunmaması | | | | | |
| 15 | Çizimlerden kaynaklanan farklılık nedeniyle sürecin yavaşlaması | | | | | |
| 16 | Çizimlerde veya tasarımda sıklıkla revizyon yapılmasının ek işlere ya da yeniden yapmaya sebep olması | | | | | |
| 17 | Tasarımdaki imalat zorluğu | | | | | |
| 18 | Malzemelerin kalitesizliği | | | | | |
| 19 | Proje hataları | | | | | |
| 20 | Yetersiz ödemeler ya da hiç ödeme yapılmaması | | | | | |
| 21 | Parasal teşviklerin eksikliği | | | | | |
| 22 | İşçi önerilerini / fikirlerini göz ardı etme | | | | | |
| 23 | Yapım yönteminin yanlış seçilmiş olması | | | | | |

DİĞER: .....

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• Şubat 2015 – Kasım 2017 tarihleri arasında Emaar Square Projesinde, projenin mimari müellif firması İki Design Group mimarlık ofisinde teknik ofis mimarı olarak çalıştı.

• Aralık 2017 – Mayıs 2018 tarihleri arasında İstanbul Aydın Üniversitesi Yapı İşleri ve Teknik Daire Başkanlığında proje mimarı olarak çalıştı.