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Research trends of Lean Construction and its compliance with Toyota Production System for year 2016

Master Thesis

International Master of Science in Construction and Real Estate Management

Joint Study Programme of Metropolia UAS and HTW Berlin

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By

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Conceptual Formulation

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International Master of Science in Construction and Real Estate Management
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Date 24. 02. 2017
Conceptual Formulation
Master Thesis for Mr./Ms. Bhaumikkumar Koladiya
Student number *s0545727*

Topic:
Research trends in Lean Construction and its Compliance with Toyota Production System in year 2016

Lean technique has potential to improve productivity in construction industry by adopting knowledge from manufacturing industry. It has been researched that how lean principles complements construction industries for various stages of construction and different type of constructions. So, there is need to structure these research in a single document to have better understanding of past development and future requirements.

The objective of this thesis is to structurally analyze how lean research has developed through years. Also, to find out how these researches are focusing on basic lean principles. The results of this thesis will guide researchers to focus on least developed area of lean construction.

This thesis will answer following questions,
- Which Principle of TPS have been mostly considered under researches?
- What research methods were mainly used?
- What is the contribution of different countries in research in last year?
- What are the key areas or problem in areas that requires further research?

Supervisors for the thesis from Helsinki Metropolia University of Applied Sciences and HTW Berlin University of Applied Sciences will be Prof. Dr. Nicole Riediger and Mr. Ammar Al-Saleh.

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Abstract

Lean construction tools and researches roots back to Toyota Production System (TPS). There are very few studies available which analyses lean construction literature regarding TPS principles to identify its compliance and also not many studies stretches the overview of researches published in lean construction.The purpose of this study was to structurally organize the International Group of Lean Construction (IGLC) conference proceedings and examine its compliance towards Toyota Production System (TPS). The adopted methodology was content analysis by reviewing 123 research papers published by IGLC in year 2016.

Literature review revealed that construction should be considered as flows and process to identify and eliminate waste for successful lean implementation. Various types of waste, their origins in construction and causes are discussed to apply relevant lean principle as a solution from production industry. Tools mentioned in the IGLC studies are discussed briefly. Six step research was carried out to conduct Content Analysis on IGLC studies constructing various categories. This categorization summarized into a single table and from this table various charts generated representing trends in lean construction with the help of Microsoft Excel software.

The results of analysis suggested that overall 54% lean construction research followed TPS framework completely. The Last Planner System (22%) is most common used lean tool followed by Lean Project Delivery (21%) and West Reduction (9%) amon others. The researches which followed TPS were classified into four main categories of TPS framework (Philosophy (15%), Process (69%), People & Partners (4%), and Problem Solving (13%)) and others (50%) were assigned Non-TPS categories according to their context. Further trends are presented in form of charts like Case Study research (43%) & literature research (24%). The findings are compared to similar study in past to add time aspect in lean research trends. This result provides guidance to future researchers in Lean Construction about demanding research areas in construction like human aspects of lean and suggests not to limit their work for only particular sectors of construction like Building Construction (40%) & Infrastructural works (5%). Results can also be used as a reference to avoid duplication of work which is already explored and to develop those works a step further.

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List of Abbreviations

5S : Sort, Straighten, Shine, Standardize, and Sustain

AEC : Architecture, Engineering, and Construction

ABC : Activity Based Costing

ABS : Agent Based Simulation

AR : Action Research

BIM : Building Information Modelling

CBA : Choosing By Advantages

CPM : Critical Path Method

CSM : Current State Mapping

DSC : Design Science Research

FSM : Future State Mapping

HMLV : High Mix Low Volume

IGLC : The International Group for Lean Construction

JIT : Just in Time

LCI : Lean Construction Institute

LPS : Last Planner System

MIT : The Massachusetts Institute of Technology

PPC : Percentage Plan Completion

SMED: Single Minute Exchange of Dies

TFV : Transformation, Flow, Value

TPS : Toyota Production System

TQM : Total Quality Management

TVD : Target Value Design

VSM : Value Stream Mapping

USA : United States of America

List of Symbols

α : Krippendorff's co-efficient to measure reliability in content analysis research.

D_e: Possible disagreement (in number) when chance prevail.

D_0: Observed disagreement (in number).

% : Percent

= : Equal to

CHAPTER 1. INTRODUCTION

This section will provide background and introduction to the thesis. It starts with general background of Lean construction and its origin from Toyota Production System, followed by research problem, research objectives and questions to be answered at the end. Afterwards stated delimitation and assumption regarding this thesis made by author. Lastly overview of thesis structure is presented.

1.1. Background

Construction industry is relatively slow in implementing innovation to improve efficiency of the project. However, uniqueness of construction projects raises a challenge in adoption of innovations. With growing demand, the construction industry must improve its productivity and quality by integrating modern advances to cope up demand and supply. The lower productivity in the construction industry may be explained by following reasons:

- Different stakeholders may have different requirements in the project.
- There is no standard technique which can help in employing the experience earned from previous projects.
- It lacks fixed assembly or production line like other industries e.g. manufacturing.
- Conflict of ideas on executing project and slow decision making may halt the progress of the construction project.

Lean construction is one of those innovations which was developed to reduce the effect of above mentioned reasons of lower productivity inspired from lean production success. Toyota motors created lean production system (also recognized as Toyota Production System or TPS). It has been researched that how lean principles complements construction industries for various stages of construction and different type of constructions.so, there is need to structure these research in a single document to have better understanding of past development and future requirements.

1.2. Toyota Production System

Toyota Motor Company developed a new system for production to survive the competition in Automobile industry after losing war in 1945. In year 1950, TPS was developed on the shop floor by Taiichi Ohno and his team with principles of Jidoka, years of practice experience and ideas borrowed from US. Japanese government noticed TPS system when Toyota was recovering faster than other companies in global recession of 1973 due to oil crisis. By the 1980s, it was only focused on cost, Mass production and cost reduction.

Later the quality concept was introduced by quality experts like Joseph Juran, Kaoru Ishikawa and others. In the 1990s, MIT published its research work on auto industry the Machine That Changed the World[1]. It introduced the world to lean production system which was concentrated by Toyota since many years. Toyota defined seven wastes in production system namely, Overproduction, Waiting time, Unnecessary transport, Over processing, Excess inventory, Unnecessary movement, defects and one added unused employee creativity. The main goal of TPS was to provide quality services to with customer satisfaction[2].

Fujio Cho developed a simple representation a house, called TPS house. This house is base of modern manufacturing process which represents a structured system with base, pillars and roof. Each element supports each other. Two pillars are Just in time and Jidoka with a base of Standardized process and Heijunka meaning leveling out production sheule[2].

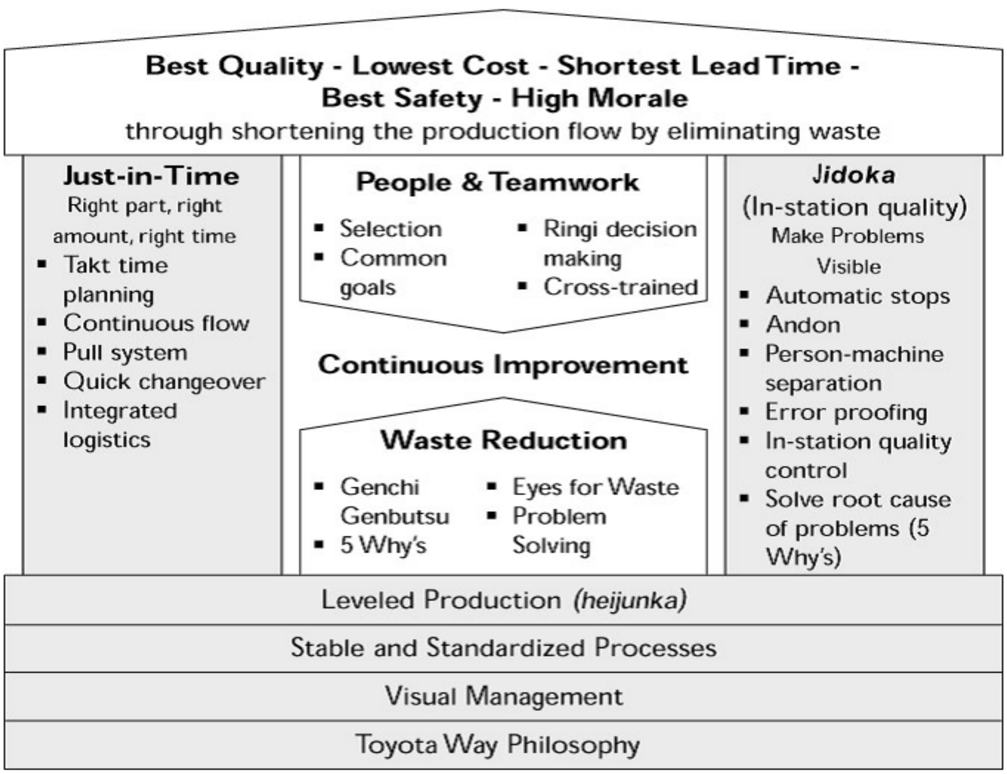

Figure 1: Toyota Production System 'House' [2]

[1] (Womack, Jones, & Roos, 1990)
[2] (Liker , 2004, p. 49)

TPS is a set of Lean tools like just-in-time, 5S, Kanban etc. which focuses on people and all the parts of this system helps to improve continuously on the process. So, these principles are accepted by professionals in engineering and business operations also[2].

1.3. Lean production

Lean philosophy or TPS system was developed and accepted as a major manufacturing approach around the world under different names. Lean production principles are evolving since its development. It was being used as a tool, manufacturing method and management philosophy. Flow of material and information was base unit for analysis in this method as most activities were affected by uncontrolled and uncertain flow resulting in not value adding activities.[3] In Lean theory, non-value-added activities were also given focus to reduce cost of them and control the flow. While in traditional production system only value-added activities were focused and improved by implementing modern technology. As a result, cost of these non-values added activities tends to raise and make the production system more fragile[3].

1.4. Lean construction

Research literature in lean construction is very less developed than that of lean manufacturing. The lack of empirical research findings in the peer reviewed journals is currently a weakness of the lean construction field[4]. Lean construction refers to the application and adaptation of the underlying concepts and principles of the Toyota Production System to construction. Like in the TPS, the focus in lean construction is on reduction of waste, increase of value to the customer, and continuous improvement. While many of the principles and tools of the TPS are applicable as such in construction, there are also principles and tools in lean construction that are different from those of the TPS[5]. Lean tools have potential to improve productivity in construction industry by adopting knowledge from manufacturing industry.

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[3] (Koskela, Lean Production in Construction, 1993)
[4] (Jørgensen & Emmitt, 2008)
[5] (Sack, Dave, Koskela, & Owen, 2009)

1.5. Research rationale

The International Group for Lean Construction (IGLC) was Founded in 1993 by international network of researchers from practice and academia in architecture, engineering, and construction (AEC) who feel that the practice, education, and research of the AEC industry must be radically renewed to respond to the global challenges ahead with a vision, "*Our goal is to better meet customer demands and dramatically improve the AEC process as well as product. To achieve this, we are developing new principles and methods for product development and production management specifically tailored to the AEC industry, but akin to those defining lean production that proved to be so successful in manufacturing"*[6]

1.5.1. Research problem

The main purpose of IGLC is to provide theoretical base to AEC industries. Till the date, they have held 24 annual conferences to share knowledge and various ideas in this field. But there are not so many studies available which stretches the overview of researches published in these conferences. So, it is very difficult and time consuming for future researchers to know state of art in particular field of development. There might be a risk of duplication of research over the same field, which is unnecessary and it will be a hurdle for advancement of AEC research community by spending resources on these non-value adding research work. Instead, these could be used for further advancement of the ideas which are already introduced and have potential implementation benefits.

TPS has been implemented as a tool, method or system and developing by various innovative technologies with the time. It is misinterpreted by many authors of lean manufacturing that TPS is collection of tools that increases efficiency and the focus for people is being vanished. "TPS is about applying the principles of the Toyota Way"[7]. In construction context, Researchers should also follow TPS in their research to get most from this philosophy.

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[6] (The International Group for Lean Construction, 1993)
[7] (Liker , 2004)

1.5.2. Research objective

There are very few studies available which analyses lean construction literature regarding TPS principles to identify its compliance. There are state of art studies available on individual principle of Lean or for particular type of construction works. Only similar study found was published in 2010 which was a result of doctoral research work and analyzed total 592 IGLC studies from 1996 till 2009[8]. In recent years, there is no such research conducted. So, one of the main objectives of this thesis is to structurally analyze and organize Conference proceedings of IGLC of year 2016 and determine how lean research has developed through the time in various construction sectors. The second objective is to find out how these researches are focusing on basic lean principles from Toyota Production System.

The results of this thesis will guide researchers to focus on least developed lean principles in construction industry and provides guidance to future researchers in Lean Construction about demanding research areas in construction. This will suggest not to limit their work for only particular sectors of construction. Results can also be used as a reference to avoid duplication of work which is already explored so that it could be developed a step further.

1.5.3. Research questions

The objectives of this thesis are to structurally organize lean construction research to reveal the trends and examine its compliance to TPS system which has four main categories consisting of 14 TPS principles[6]. This thesis will answer following questions derived from the objectives by reviewing total 123 research studies published in IGLC conference 2016.

1. Which Principle of TPS have been mostly considered under researches?
2. What research methods were mainly used?
3. What is the contribution of different countries in research in last year?
4. What are the key areas or problem in areas that requires further research?

[8] (Jacobs F. , 2011)

1.6. Delimitation

- This thesis with review IGLC conference proceedings for year 2016 only.
- The studies analyzed are strictly limited to term “Lean construction” because IGLC database includes lean research in construction sector only.

1.7. Assumption

Following assumption was made for this thesis.
IGLC represents most research works in Lean Construction: There are other organizations like Lean Construction Institute, European Group of Lean Construction, Project Production System laboratory, Lean Project Consulting etc. applies lean principles in construction, but they do not have sufficient database as compared to IGLC database.

1.8. Structure of thesis

This chapter represented initial background about the subject, motivation for research and problem statement.

Chapter 2 will discuss about relevant literature for lean construction and its origin from TPS. Readers will be introduced to various type of waste in construction and lean tools could be used for reducing waste through lean construction.

Chapter 3 describes research methodology adapted for the study and it’s relevant to the research problem. It will present six step method for content analysis which includes validity and reliability of the research. This chapter will also cover creation of each category for analysis and brief description.

Chapter 4 will conclude the results of analysis in form of graphs and charts. Research questions will be answered in this chapter.

Chapter 5 discuses about the trends in lean construction research. The results of this study will be compared to the similar study from past to have general overview of research interest and trends over time.

Chapter 6 draws conclusions from the results & discussions and summarize thesis.

CHAPTER 2. LITERATURE REVIEW

Lean theory from manufacturing industry has been widely accepted by many other industry and presented visible benefits. In order to determine the value put on the TPS framework in lean construction research, a review of literature on the history of lean development in construction is important. This chapter will start from reviewing literature of lean production. Then it will discuss relevance of lean in construction. To understand and implement lean it is necessary to understand waste in construction industry because lean is ultimately elimination of waste from the process. This chapter will discuss various construction waste and lean tools to eliminate those waste. Lean tools described in this chapter are previously used and tested by various professional in construction field. These tools are originated from lean manufacturing from Toyota Production System. It is necessary to study these tools in order to examine and analyse the research studies in compliance with TPS. It will give readers an understanding about various lean terminology and overview of usefulness of lean tools.

2.1. Lean production

Lean production is based on value generation which is gain by reducing wastes and non-value adding activities in manufacturing process. The whole production system is managed in such a way that it gives a value to end user. It focusses on total time and cost of the project rather than individual time and cost of activities engaged with the project. Each activity is coordinated by one schedule and it is followed by people from organisation who sets the project target and performance. Value for customers, for the process and single flow of information towards the finalisation is the main goal in Lean Production theory[9].

Koskela[10] summarised following principles which ensures increase in efficiency to control and improve the flow in Lean Production theory. These principles have been improvised and evolved in various fields to control the flow design and process.

1. Reduce non-value adding activities.
2. Organize production as a continuous flow.
3. Increase output value through systematic consideration of customer requirements.
4. Reduce Variability.
5. Simplify by minimizing the number of steps, parts and linkages.
6. Increase output flexibility.
7. Increase process transparency.
8. Focus control on complete process.
9. Build continuous improvement into the process.
10. Reduce cycle time.
11. Benchmark.

All these principles are applied for continuous improvement framework for evaluation of production process. Earlier innovation was used as an evaluation of production which is more diverted towards conversions opposite to continuous improvement where the goal is flow. There were several problems in traditional measures,

[9] (Liker , 2004)
[10] (Koskela , 1992)

- They do not lead to continuous improvement and do not give indirect cost sources which diverts focus point[11],
- They measure after the fact and they collect too much data especially in computerized system[12],
- They lead to local optima instead of global optimum[13].

In lean theory, new measurement were developed to support this new principle which includes following Measurement requirements[12].

Measurement of,

- Waste to support waste reduction.
- Added value in each step to reduce non-value adding activity.
- Variability and defects to reduce variability.
- Cycle time of all main and sub-processes.
- Simplicity/complexity.
- Transparency to make visible all the processes so people can receive direct feedback at both global and local level.
- Focus on causes then results.
- Status and rate of improvement, to implement the potential for improvement, trends are more valuable than fix numbers.

To implement this philosophy there are four main factors needs to be balanced[12],

- ➢ Management commitment for opening ways for change.
- ➢ Improvable and measurable focus for example cycle time for continuous improvement.
- ➢ Employee involvement.
- ➢ Learning tools, techniques and principles of process management by small tests.

To conclude, Lean theory is flow process of material and information which are controlled for minimal variation and cycle time, improved continuously regarding waste and value and periodically for efficiency by implementing new technology[12].

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[11] (Johnson & Kaplan, 1987) in (Koskela , 1992)
[12] (Plossl, 1991, p. 189) in (Koskela , 1992)
[13] (Umbel & Srikanth, 1990, p. 270) in (Koskela , 1992)

2.2. Lean theory implications for construction Industry

Lean in construction can be viewed as an amended replica or desired replica of the TPS framework used in manufacturing[14]. Construction differs from manufacturing based on its physical features and the outcome of the end product. For example, in manufacturing, finished goods generally can be moved in whole to be stored by retailers or end consumers[10]. Clear alignment of the TPS framework to the construction operating platform is an ongoing challenge in the construction industry based on the fact that construction operates on a different operating platform than that of manufacturing[14].

On the other hand, construction activities are same as those in manufacturing industries. This has been also used in previous construction methods like CPM network where activities are basic unites for analysis. Some managerial concepts like systematic project realization, hierarchical organization and ignorance of quality are also based on this activity oriented system in both construction and manufacturing industries. There was lack of unique framework that can be used or this activity based conversion model and, manufacturing has always been a source for innovation in construction. So it was required to re-develop construction as flows after its success in manufacturing and the first step towards this was to change the thinking concepts rather than finding solutions for every other problems[10].

Design and Construction are two main process of a construction project. The other supportive process are management process of design and construction which leads to project management. All these are characterized by Cost, Time and Quality of project. Quality is measured by the performance of product and its less defectiveness which in other term is Value. Cost and time will be evaluated by value adding and non-value adding activities. In design, the focus is on maintaining the value through design process and in construction the focus is on reducing waste to maintain the cost and time[17].

Since construction projects are one of a kind project, it is required to analyse it with two reference point, short term and long term. For, short term evaluation project should be finished within allowable limits and as a long-term viewpoint, the process in construction

[14] (Koskela, 1999)

should be the best in available market to be leader in market. In any case the process in construction should be continuously improvised.

Conventional methods are not able to measure waste in process because it only focuses on cost and time. So, there is a new mode of measurement required for attempting continuous improvement which are same as those of manufacturing namely, *Waste, Value, Cycle time, and Variability* as mentioned in section 2.1.

But to measure it in construction, there are problems to overcome because of following peculiarities[15],

- One of a kind nature make it complex to compare
- Collect data from construction site is also difficult
- Procedure and definitions of data-collection are changing

These peculiarities can be the reason for inefficient construction flows. But after clearly understanding them, it can be improved with lean theory.

Problem of one of a kind nature and uncertainty in activities can be solved by standardizing the process or activities in process and providing buffer in between the activities. Data collection and sharing can be improvised by minimizing temporarily organizational interfaces, team building during project and integrated flow through partnership. Variability in procedure can be reduced by detailed and continuous planning and systemized work procedures.

Overall, Lean approach evaluates existing construction flows, guides to identify potential improvements. It can find and solve problems in construction process flows. Elimination of construction peculiarities puts the construction and manufacturing industry on the same page[18]. The Quality assurance and Total Quality Management has been first step of production technique to construction starting from construction material, parts like doors & windows towards design and construction[18].

[15] (Koskela , 1992)

2.3. Lean principles for construction

Koskela[16], Howell[17], Picchi[18], Womack Jones and Roos[19] have explored lean principle originated from TPS for construction. The Construction industry institute gathered five below mentioned most relevant and fundamental lean principles from all lean construction research works[20]. These is understood as a combination of the best and most relevant principles for lean construction from each researcher.

- Standardization
- Culture/People
- Continuous Improvement/Built-In Quality
- Eliminate Waste
- Customer Focus

Waste elimination is furthers divided in four parts: process optimization through process itself, process optimization through supply chain management, process optimization through production planning and product design optimization through constructability review process.

All these five principles are divided into sub-principles to include all important principles related to construction which are mentioned in table 1 below. There are certain barriers to implement these principles in construction. Definition of waste in construction and manufacturing is different. Transmission of lean knowledge is lacking shortage of the new theory related to construction. This can be justified by following investigation described in section 2.4 of waste in construction[16].

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[16] (Koskela, 2000)
[17] (Howell G. , What is lean construction, 1999)
[18] (Picchi, 2001)
[19] (Womack, Jones, & Roos, 1990)
[20] (Diekmann, Balonick, Krewedl, & Troendle)

Table 1: Lean construction principles and sub-principles[21]

Principle	Subprinciple
Customer Focus	1. Meet the requirements of the customer. 2. Define value from the viewpoint of the customer (project). 3. Use flexible resources and adaptive planning to respond to changing needs and Opportunities. 4. Cross train crew members to provide Flexibility. 5. Use target costing and value engineering.
Culture/People	1. Provide training at every level. 2. Encourage employee empowerment. 3. Ensure management commitment. 4. Work with subcontractors and suppliers to regularize processes and supply chains.
Workplace Organization/ Standardization	1. Encourage workplace organization and use of the 5S. 2. Implement error-proofing devices. 3. Provide visual management devices. 4. Create defined work processes for repetitive tasks. 5. Create logistic, material movement and storage plans that adapt to changes in workplace configuration.
Waste Elimination Part I (Process Optimization)	1. Minimize double handling and worker and equipment movement, Reduce Changeovers 2. Balance crews, synchronize flows 3. Remove material constraints, use kitting, reduce input variation, Reduce Scrap

[21] Created in conformity with Lean construction wheel from (Diekmann, Balonick, Krewedl, & Troendle)

Principle	Subprinciple
Waste Elimination, Part II (Supply Chain)	Institute JIT delivery, supply chain management
Waste Elimination, Part III (Production Scheduling)	1. Use production planning and detailed crew instructions, predictable task times 2. Implement last planner/reliable production scheduling/short interval production scheduling 3.Practice last responsible moment/pull scheduling 4. Use small batch sizes, minimize WIP 5. Use decoupling linkages, understand buffer size and location
Waste Elimination, Part IV (Product Optimization)	1. Reduce parts count, use standardized parts 2. Use pre-assembly and prefabrication 3. Use pre-production engineering and constructability analysis
Continuous Improvement and Built-In Quality	1. Prepare for organizational learning and root cause analysis 2. Develop and use metrics to measure performance; use stretch targets 3. Create a standard response to defects 4. Encourage employees to develop a sense of responsibility for quality

•

2.4. Construction waste

Lean production was developed to eliminate waste from the processes and maintain continuous work flow throughout. To apply lean principles in construction, it should be developed as a set of processes & flows. Then waste must be identified from these flows and eliminated. In this study, various types of waste, their origins in construction and causes are discussed to apply relevant lean principle as a solution from production.

Construction is inevitable part of human life and world economy. Construction industry all over the world produces waste. According to Mike Baker[22], More than 400 million tonnes of materials get delivered to site each year. Of these 60 million tonnes go straight to tip due to over ordering, damage resulting for poor storage or because of inappropriate ordering. All these waste goes to landfill and results in environmental problems. Construction is set of activities so it can relate project management instead of operations and it has phases with attribute of labour, cost and time[23]. Each stage of project needs certain decisions regarding its attributes of time, cost or labour which will affect the construction process and produce waste. This waste can be varying according to the size of project and number of decisions[10].

To reduce these waste or non-value adding process change in thinking is necessary. Construction process should be considered as flow. Flow improvement should be associated with management to reduce these waste.

Lean in simple form is waste elimination from all the activities of project for efficient delivery via value-adding activities. Lean tools have been developed by various researchers to improve these flow and apply lean theory in construction to complete a project with quality, also within budget and schedule. Comprehensive list of all the lean tools mentioned by the researchers in IGLC conference proceedings in year 2016 is described in the next section 2.6.

The definition used by Koskela[9] are being used as a basis for lean construction suggesting to reduce non-value added activities from the process. The different type of waste stated in following section 2.5.

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[22] (Baker, 2008)
[23] (Koskela, 1996)

2.5. Type of waste in construction

Table 2: Type of construction waste[24].

Material waste due to:	Waste in time due to:
Overproduction	Idle (waiting periods)
Wrong storage	Stoppages
Theft or vandalism	Clarifications
Over ordering/ excess	Variation in information
Wrong handling	Re-work
Manufacturing defects	Ineffective work (errors)
	Interaction between various specialities
	Delays in plan activities
	Abnormal wear of Equipment

Table 3 gives origins and causes of waste in construction.

Table 3: Origin and causes of construction waste[24].

Origins of waste	Causes of waste
Contractual	• Errors in contract documents • Contract documents incomplete at commencement of construction
Design	• Design changes • Design and construction detail errors • Unclear/unsuitable specification • Poor coordination and communication (late information, last minute client requirements, slow drawing revision and distribution)

[24] (Dajadian & Koch, 2014)

Procurement	• Ordering errors (i.e., ordering items not in compliance with specification) • Over allowances (i.e., difficulties to order small quantities) • Supplier errors
Transportation	• Damage during transportation • Insufficient protection during unloading • Inefficient methods of unloading
On-site management and planning	• Lack of on-site waste management plans • Improper planning for required quantities • Lack of on-site material control • Lack of supervision
Material storage	• Inappropriate site storage space leading to damage or deterioration • Improper storing methods • Materials stored far away from point of application
Material handling	• Materials supplied in loose form • On-site transportation methods from storage to the point of application • Inadequate material handling
Site operation	• Accidents due to negligence • Equipment malfunction • Poor craftsmanship • Time pressure
Residual	• Waste from application processes (i.e., over-preparation of mortar) Packaging
Other	• Weather • Vandalism

2.6. Lean tools

There are various lean tools which can be used to improve construction process and its performance. In this section, all those lean tools are discussed briefly which were mentioned in IGLC studies in 2016.

2.6.1. Lean project delivery

The Lean Project Delivery System is a set of interdependent functions, rules of decision making, procedures for execution of functions, and as implementation aids and tools, including software when appropriate, and is a conceptual framework developed by Ballard[25] for Lean implementation in construction and project based construction system. It is a method of applying appropriate lean tool at required phase in the project to make project delivery successful up to the agreed level.

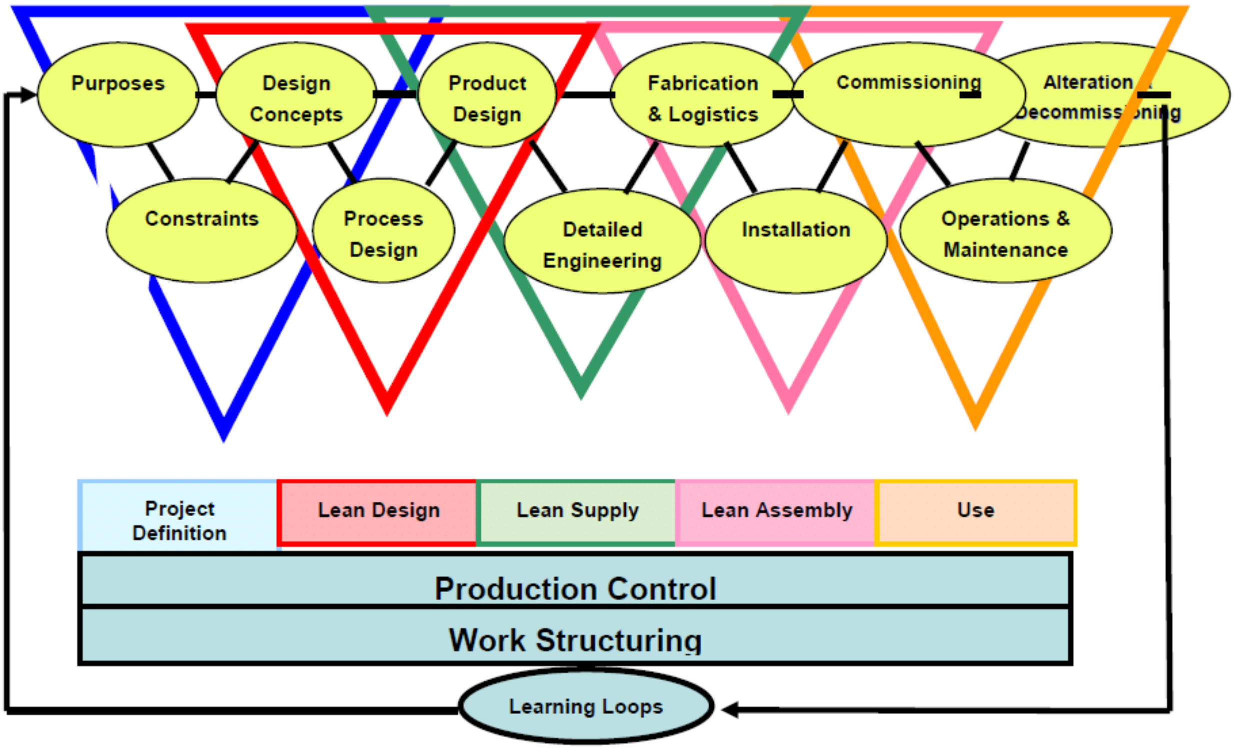

Figure 2 : Lean Project Delivery System[26]

The Lean Project Delivery System includes 15 interconnected modules with two modules production control and work structuring linking each phase to the next level. Use

[25] (Ballard, 2008) in (Aziz & Hafez , 2013)
[26] (Construction Industry Institute (CII), 2007)

of this tool will depend on scope and complication of a project. It starts from the beginning and involve all the stakeholders.

Advantages includes[27],

- Better value, quality and cost.
- Clear communication and base for collaboration.
- Common target for improvement and review.

2.6.2. Last Planner System

Last Planner System (LPS) is one the most used and widely known Lean tool for management in construction. It involves workflow and production controlling units. Work flow is being controlled by Look Ahead meetings and Production flow is controlled by weekly work planning. It identifies variations in workflow and removes risk from the process by involving "last planners" foreman in decision process. The main goal of LPS is to involve workers into continuous improvement process and make the flow of work at highest possible efficiency.

LPS comprises Master plan. Phase Plan, Look Ahead Plan, Weekly work plan, and percentage of plans that are timely completed or PPC: Percentage Plan Completion. It also discusses about the incompletion causes[26]. PPC is a measure for evaluation of effectiveness of LPS system. It does not reflect production directly but when PPC is good it means there are less variations and uncertainty in the process which produce less waste and more amount of production. In LPS the sequence of SHOULD-CAN - WILL-DID is being implemented by site foreman. A plan will be decided from the planned schedule (SHOULD) and current condition (CAN) on site, which is WILL be done. The last planner is responsible for selecting these activities which is realizable according to present resources and material, so the job can be fulfilled completely. The image below shows LPS graphically.

[27] (O'Connor & Swain, 2013)

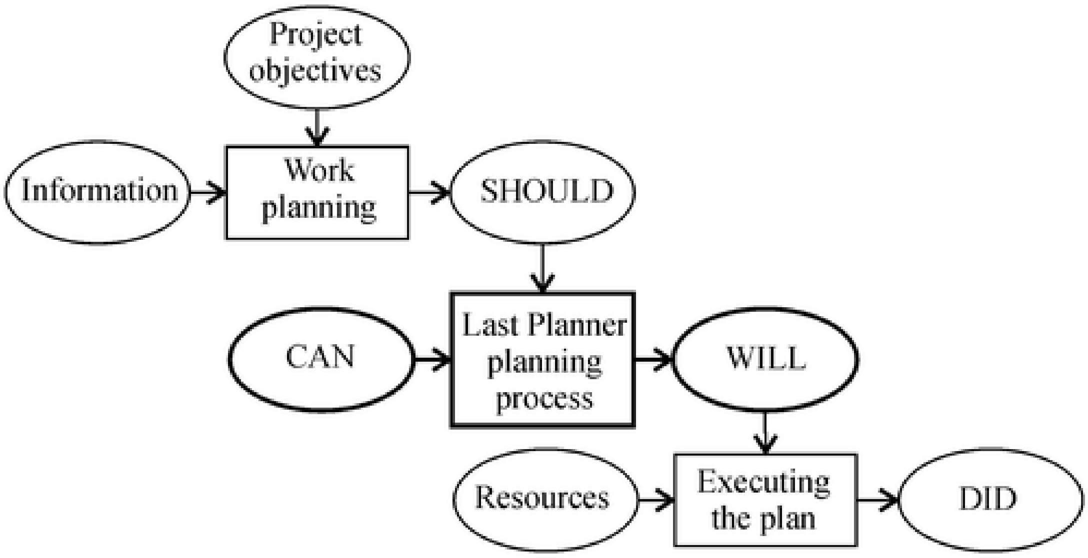

Figure 3: The Last Planner System[28]

The benefits of using LPS can be summarized as follows[29],

- Levelled work flows.
- Foreseeable work plans.
- Reduced cost and time of project delivery.
- Increased productivity with more collaboration with field personnel and management.

2.6.3. Problem solving tools

Problem solving tools are being used as team approach when there is need to solve issues or defects which may affect the completion of program. Issue could be related to cost, quality, safety or productivity and the goal is to fund the root and cause of that issue to complete the task by new best way possible.

Related tools for problem solving:

2.6.1.1. A3 Problem solving

A3 sheet of standard template is used when associated team deals with the problem. It makes sure to follow structured procedure to identify the root cause of the problem suggesting the measure to solve the problem[27].

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[28] (Howell & Ballard, 1998)
[29] (Aziz & Hafez , 2013)

2.6.1.2. Fishbone analysis

Fishbone analysis is process of visual brainstorming to identify most probable causes for the problem which is also known as Ishikawa diagram. In this diagram, a standard template of a shape of fish-bone structure is used. At the head of fish, the problem is written and the probable causes are written under the title of material, person, method, environment or person. After identifying the problem, a weightage is given according to the effect of cause on main problem. This weightage number helps to quantify the results or the cause of the problem to make decision faster. This factor is used for the next step, Five Why Analysis[27].

2.6.1.3. Five “Why” analysis

When we have a specific problem to focus from Fish-bone diagram, it will be analyzed with ‘why’ question for five times to go into the root of the problem. By asking ‘Why‘ for five time we will have reason for each cause and we can reach up to the root. Then measures will be suggested and noted down in A3 sheet[27].

2.6.1.4. Plan-Do-Check-Act (PDCA)

Plan-Do-Act-Act cycle also named as improvement cycle, is a process improvement approach represented as a circle with no ends which symbolizes the cycle of repetition[27].

These problem-solving tools have following advantages for a construction project,

- Improvement in predictability.
- Reduced variability.
- Less waste in process.
- Increased efficiency in cost, quality, safety and delivery.
- Client and customer satisfaction.

2.6.4. 5S Workplace Organization

5S is basis of lean thinking and continuous improvement. It comes from Japanese words Seiri, Seiso, seiton, Seiketsu and Shitsuke (meaning Sort, Straighten, Shine, Standardize, and Sustain). It provides the organization of work area for safe and effective operation which reduces the waste. It mostly applied by the people who work in area so improvement in the process can be attained[30].

As the name suggest it consist of five steps of Sort, Straighten, Shine, Standardize, and Sustain. Sort the important item to perform the activity and separate it from the non-important items to save time in searching for that when needed. Set a location for each required item to use and keep it safe at single and easily reachable location. Keep the work area clean and organized to maintain standard of workplace and good working order. Set and maintain the standard to achieve productivity at desired level. Sustain it through training and inspection.

Advantages of applying 5S on site are[27],

- Introduce safe work place.
- Increase in productivity by saving time from wasteful activity.
- Set working standard on site.
- Make easy to identify probable problems.
- Supports visual management.
- Improves morale and image of work environment.

2.6.5. Visual Management

Visual management gives information about the planned work, current progress and the problems during the work visually which is easy to check and understand. It is already being used in different forms like fire extinguishers or other hazards items. For lean systems it would be used for color coded traffic, performance analysis by charts, issue and actions, etc. Amount of work to be done by given time and rate of performance require, marking on floor and storage for tools and instruments for safe and effective work environment will be supported by Visual management. Good systems

[30] (Liker , 2004, p. 171)

have constant high performance through active communication through visual management. It easily give idea or explain the situation or give status of problem so that further action can be taken. Further advantages are[27],

- Improvements in productivities and quality.
- Builds image and standard of site, organization and operation.
- Work in collaboration.
- Team ownership for project delivery.
- Safe and effective working conditions.

2.6.6. Process Improvement

Process improvement suggest improving the process during project delivery or organization to make them more efficient. The main objective is to reduce the total lead time to complete the project with end to end process and with lean flow.

It has two basic steps[31]:

Current state mapping (CSM): Here present situation of project process is being analyzed to have an overview about the issues, delays, qualities, bottlenecks or excessive process etc. CSM provides foundation to design of future state process.

Future State Mapping (FSM): FSM is improvised process from CSM with applicable lean principle (5S, Visual management) to make overall workflow more efficient. Roles and responsibility for management and control are well defined and clear to make process more effective.

Process mapping is commonly used for process improvement. Leader from every process will discusses the flow of work, how it is progressing and what can be done to improve it. Maps are generated on big walls to make it visible.

Types of flow maps[31]:

2.6.1.5. Process of activity flow map:

Most common type of flow map used in construction with current and future state map with boxes as process and diamonds represented as a decision. They are interlinked with each other by arrows which depicts the direction of work-flow.

2.6.1.6. Swim lane map:

Swim lane process map is similar as process of activity flow map with a difference in process step which is carried out by individual engaged in the process. This type is useful when there are activities are happening simultaneously. It also gives the responsible person of any particular process to control the process. Each one calculates the waste during each step.

2.6.1.7. Supplier, input, process, output, customer map:

This is used to focus on customer. It is also known as right to left mapping where starting is from the definition of output demanded by customer. Then the process are designed to meet the output. This mapping series is repeated in all stages of construction.

2.6.1.8. Value stream mapping / analysis:

VSM is used to define and analyze the flow of material and information required for the project. It can be applied to any value stream. VSM needs time and efforts so it is used to process flows and material for high value project where construction is repetitive. Team records all the details from plans and create map based on design tehri work and how it will affect the work of others. This map is updated regularly and ensure the streamlined work flow. Its advantages for construction are[27]:

- Maximizing customer value by best possible way to execute process.
- Improvement in forecasting and productivity.
- Clarification on roles, responsibility and processes.
- Reduction in waste of time, cost and labor.
- Reduction in lean time.

2.6.7. Choosing by advantages

CBA is lean tool which is used for decision making by multiple criteria decision analysis developed by Jim Suhr[31].It uses correct data and in correct method with basis of questions, facts, and the important of differences between advantages of alternatives. It

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[31] (Suhr, 1999)

makes construction process less subjective decision-making process when deciding amongst the alternatives[33].

CBA discovers only advantages of the alternatives opposite to the traditional where both advantages and dis advantages are considered to avoid double counting and ommisions[33]. CBA separates cost from value while cost is constant and should be given special attention during decision[32]

It concentrates on the customer and maintains Liker's principle 14 from 'The Toyota Way' make decisions gradually by agreement, thoroughly seeing all options before applying quickly. Using CBA, teams make thorough conclusions that allow them to move forward with confidence.

Choosing By Advantages has become the preferred decision-making approach for many project team, together with many projects using Integrated Lean Project Delivery[34]. The CBA system presents several phases, ranging from the stage-setting phase, an innovation stage, the decision-making phase and the implementation phase[33].

2.6.8. Waste Reduction

Main function of lean thinking is to reduce waste. It is mentioned here as a separate tool to refer a category of group of research study who apply tools related to waste reduction to achieve sustainable development goal. As shown in figure below Lean and Green both complement each other and main objective of both theory is to reduce waste. In this text it is considered as a tool to achieve green goals with support of lean theory. Here waste reduction could be achieved by various lean tools like Value stream mapping, 5S, Visual Management etc. it seems that lean and green are measured as two distinct contexts which contains the waste. Though, the classification of waste is not the same in lean and green. While the removal of some lean waste can convey environmental benefits, the removal of other lean waste sources does not essentially improve environmental performance.

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[32](Karakhan, Gambatese, and Rajendran,2016)
[33] (Dave, Koskela, Kiviniemi, & Tzortzopoulos, 2013)

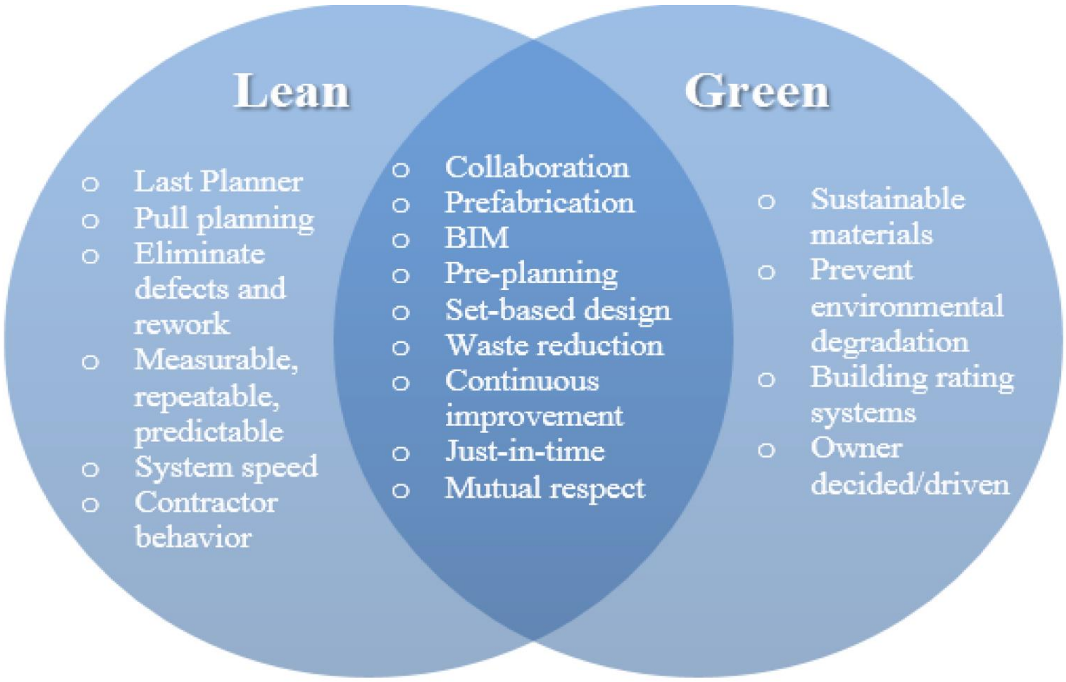

Figure 4 Venn diagram for Lean and Green practices[34]

2.6.9. TFV theory

There are value adding and non-value adding activities in system with flow of material information, labor and external elements like weather etc. value adding activities are transformed into customer satisfaction and there are three stages in system for adding values.

Design stage with detailed planning from conception to completion, Information management with detailed scheduling and material procurement, transformation stage with conversion of all material and information into a product that was demanded by customer[10]. Lean construction gives idea about combined insight and application of conversion (also known as Transformation) flow and value management (altogether known as T.F.V. Management theory) with purpose of value creation for customers.

[34] (Maris and Parrish, 2016)

Koskela used ‘world views’ to define the three values transformation, flow and value. Transformation realize the value which is ‘What’ part, Flow reduces the non-value adding activities which is ‘How’ part and Value improves customer satisfaction which is ‘why’ part of reality[16].

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

Figure 5 T.F.V. Principles[16]

2.6.10. Target Value Design

Target value design is limiting the construction and design of a project up maximum cost. Each project has to finish within certain financial limit set by client to be considered as successful. In TVD, this initial scope is completed below market cost and also the expected cost falls down with the progress of design[35]. A validation study is important for TVD with an investigation of allowable and expected costs to thoroughly evaluate business feasibility. The plan validity is done by main members of project delivery team, if funded. Designing process of target costing involves systematic method which[36],

1. Allocate the target cost to systems, subsystems and components.
2. Have cost modelers to provide cost guidelines to designers up front, before design begins.
3. Incorporate value engineering/value management tools and techniques into the design process.
4. Use computer models to automate costing to the extent feasible.

The important part here is budget as a decision maker for design instead of a result of design.

2.6.11. Just-in-time

As defined by American Production and Inventory Control Society (A. P. I. C. S.), Just In Time is," A philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product. The primary element of zero inventories (synonym for J. I. T.) are to have only the required inventory when needed; to improve quality of zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum cost. In the broad sense, it applies to all forms of manufacturing job shop and process as well as repetitive[36]"

[35] (Dave, Koskela, Kiviniemi, & Tzortzopoulos, 2013)
[36] (American Production and Inventory Control Society, 1992)

It is about eliminating buffer between processes but construction is not stabilized process so, there should be elimination of uncertainty and variation. So Ballard[37] proposes a strategy for JIT in Construction:

3. Better location and sizing of schedule buffer,
4. Immediate implementation of planned buffer and make ready process in front of production process,
5. Progressive replacement of schedule buffer by planned buffers.

2.6.12. Takt time planning

Applying lean principles in construction needs continuous flow as a first step. Creating continuous flow enforces the implementation of several lean tools such as visualization and continuous improvement strategies, of which the main prerequisite is takt time[40]. Takt time is the time set for the supply of a certain process and is derived from the customer demand. "It is the heart beat of one piece flow[41]". Takt time, in construction projects, is the overall progress rate at which all construction process are ideally tends to work. If it goes at a rate faster than takt, buffers will increase until they are considered excess inventory and becomes a waste. However, if it goes at a rate slower than takt, activities will take longer than their ideal concluding time and will thus delay successor task causing an insufficient production rate, unable to accommodate for the client's need[38].

Implementation process for takt time planning requires iteration of following steps[40]:

- Gather information.
- Define areas of work (zones).
- Understand the trade sequence.
- Understand the individual trade durations.
- Balance the workflow.
- Establish the production plan.

[37] (Ballard & Howell, Towards construction JIT, 1995)
[38] (Yassine, Bacha, Fayek, & Hamzeh, 2014)

2.6.13. Set based Design

Set based design involves a set of alternatives of design from the beginning instead of developing just one alternative in detail. The conventional ways are sequential process where designer's process step by step generally obstructs collaboration between stakeholders and produces non-value adding wastes in the project. Downstream stake holders joins the process only at later stage so their expertise is not being used in to constructive design efforts plus it will generate waste due to rework when there is an issue.

In Set based design designers will start with serval alternative and narrow it down to the best suitable one, when they have enough information to decide. The consideration of wide range of alternative gives possible to select best and avoid missing important alternative by enforcing the decision at early stage[9].
The basic idea is to apply all relevant criteria in producing, evaluating and choosing from design alternatives from the beginning of design, rather than introducing new criteria as new stakeholders come onto the team. This implies that all key stakeholders, upstream and down, such as architects, engineers, general contractors, specialty contractors, regulatory agencies, and perhaps even suppliers become members of the design team[39].

2.6.14. Heijunka

Heijunka is production leveling by volume and product mix, it considers the whole lot of order and level it down to the whole duration so it can produce same amount of and mix all the time[40]. Heijunka is another imitation of lean production's continuity priority. In visual management, Heijunka boxes are used for scheduling. A Heijunka box is a wall schedule that is divided into a grid of boxes. Each box represents an equal amount of time in a predefined time span. Some colored Kanban cards, by the type of products planned to be produced, are attached on each box to represent the time span reserved for that specific product and the upcoming manufacturing route[40].

[39] (Ballard, The Lean Project Delivery System: An Update, 2008)
[40] (HC Online, 2006)

2.6.15. Kanban

Production is pulled upstream from downstream, so there will be no process until there is signal from downstream. This signal system is known as Kanban which is Japanese word of sign card. Kanban is basic tool for JIT method. Continuous flow, weekly and monthly production schedules are essential for an effective Kanban system. A basic Kanban system's rules are as follows[41]:

1. The earlier process produces items in the quantity and sequence indicated by the Kanban.
2. The later process picks up the number of items indicated by the Kanban at the earlier process.
3. No items are produced or transported without a Kanban.
4. Always attach a Kanban to the goods.
5. Defective products are not sent to the subsequent process. The result can be 100% defect-free goods. This method identifies the process generating defects.
6. Reducing the number of Kanban cards increases their sensitivity. This reveals the existing problems and maintains inventory control.

2.6.16. High mix low Volume

High mix low volume production gives better opportunity to tailor customer needs, improved responsiveness and less inventory. TPS is suited for low mix and high-volume production where workflow is simple. HMLV are used in small scale units where production is small with high varieties.

In construction, the project be divided into two sub-projects, with the two sub-components managed individually. The first sub-project is centered on the shared components of the product - exterior, common systems, shared spaces like lobbies. The second (really a series of smaller sub-projects) is focused on building the private components of the product - each apartment's individual interior. This informational stability and repetitiveness are equivalent of mass-produced products made in a factory, and appropriate management tools can be applied. Takt-time planning and the Line of Balance method of planning and production control are very much related for the shared

[41] (Halevi, 2001)

components of the product, since the repetitiveness of the work packages give themselves readily to line balancing and corrective measures if nonconformities are noticed. This de-construction of the project into two allows optimization of each individually in accordance with its own characteristics[42].

2.6.17. Genchi Genbutsu/ Go and See

Genchi Genbutsu is Japanese word which means “go-and-see” or “go and see yourself”. It is about not taking all for granted or not trusting on outside reports. The flow of the lean production should be observed and evaluated directly by skilled people as much as possible without any middleman. Numbers and facts should be combined by observing the condition and appropriately analyzing some reliable data. This requires being involved in the flow itself at a comprehensive level, seeing the whole picture with interconnections and identifying what could be happening in future[43].

2.7. Other techniques and methods reviewed by researchers in 2016.

Agent-based simulation (ABS)

It is particularly suitable for modelling peoples’ behavior and interaction in complex settings, like in construction, and therefore represents an alternative[44]. Ma & Sacks[44] presented a parametric ABS system developed using a relational data model for modelling construction workflow; the model enables users to specify the construction subjects (subcontractor trade crews), their work methods, the amount of work, the workspaces (locations), dependencies between the works, etc. The simulation encapsulates both variability and uncertainty in the construction workflow.

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[42] (Korb and Sacks,2016)
[43] (Tezel, 2007)
[44] (Ma & Sacks, 2016)

Activity-based costing (ABC) technique

Activity-based costing (ABC) is a costing model that identifies activities in an organization and assigns the cost of each activity resource to all products and services according to the actual consumption by resource and activity[45]. ABC is found to provide management with a more detailed cost analysis of activities and processes[46]. ABC uses two stage costing, different from resource based costing which assigns resources to products, traces resources to process and then assign process to the products. It has mainly used been used to allot overhead costs in construction[46].

Agile design management

To manage design phases in construction, dynamic methods are needed. Agile Design Management is an iterative management system based on short cycles and rapid feedback loops in order to continuously arrive at the perfect solution[47]. It is the adaptation of the Scrum approach into the design phase of construction projects. The goal of Agile Design Management is to increase coordination, interface management, collaboration and transparency throughout all design phases. The use of agile design management is restricted to logistics, production facilities, laboratories and some office buildings47.

Make Ready Process

Make Ready Process guarantees that all the known constraints on the remaining activities are identified, planned, and resolved before they impact the required dates of the downstream activities[48].

Stigmergy

Stigmergy is a mechanism comprising a sensing agent that responds to the settings of the environment by performing an action[49]. It is a biological mechanism to explain self-organization at society level, meaning how insect colonies look perfectly organized and coordinated as a whole when every insect is naturally following its own schedule without recognizing the bigger picture. The implication for humans exist in how simple or-

[45] (Cokins, 1996) in (Kim & Kim, 2016)
[46] (Kim & Kim, 2016)
[47] (Demir & Theis, 2016)
[48] (Ballard & Howell, 1995)
[49] (Khaddaj, Kachouh, Halaby, & Hamzeh, 2016)

ganisms are skilled of constructing complex habitations through their dynamic interactions. Social insects' behavior is comparable to essential theories of Lean construction Management. A study by Khaddaj[49] tried to explore synergies between lean and Stigmergy. Findings of the study disclose that the natural mechanisms of Stigmergy can aid the operations of a Lean environment[49].

Single Minute Exchange of Dies (SMED)

The main application of SMED is the transformation of internal activities of the setup stage to external activities[50]. In terms of project management, internal activities are in the critical path, while external activities are parallel to the critical path. Hence, in a project-driven process, the application of SMED means removing activities that are not hardwired to the critical path and executing them in parallel, furthermore, resulting in a compressed critical path. In the end, SMED practices in project management can be seen as a method for fast tracking the project schedule[50]. Offsite fabrication is one example of application of SMED. SMED practices that focus on reducing set-up times (transient time).

Computational case study

Buffer sizes between production places are one aspect that effects production performance. Current practices in precast production ignore buffer size between places typically make impractical production plans[51]. Computational techniques was used in this case study to analyze the impact of buffer size between places on production makespan and costs[51]. A limited buffer size between places is taken into account in the study. Case study shows that if the provided buffer size is sufficient for the needed buffer size, both makespan and total penalty costs could be reduced[51].

Manual analysis of buffer is time consuming and complex between precast fabrication places. Computer experiments could help to make best suitable decision. Production resources, mold type and amount, working hours, allowable overtime, and buffer sizes could be simultaneously considered in the developed application programmed using JAVA language[51]. These computational techniques may assist managers in arranging production plans with a sufficient manner, and provides alternative production plans for decision-making[51].

[50] (Antunes, González, & Walsh, 2016)
[51] (Ko, 2016)

Lean core elements

The table below shows core elements in Lean and relevant technique to the principle. The core elements in Table 4 represent, transitional level of detailing, about what a lean firm should aim, to achieve their target and objectives. These elements can support in designing the organizational process and developing or selecting relevant lean tool for that.

Table 4: Lean core elements[52]

Objectives	***Princples***	***Core elements***		***Examples of related techniques***
Permanently improve company's competitiveness by: - eliminating waste - consistently attending client's requirements in variety, quality, quantity, time, price	VALUE	Enhanced product / service package value	Solution that enhances value for the client	Identification of what is value for the client, services aggregation, business re-structuring
			Product variety	Modular design, interchangeability, fast set-up, planned variety compatible with production system
		Time based competition	Production lead time (order to delivery)	Small batches, product family factory lay-out, JIT
			Product development lead time	Black box system, heavyweight manager, set based design, concurrent engineering
	VALUE STREAM	High value adding in the extended enterprise	Value stream redesign eliminating waste	Mapping, combining activities, eliminating non-adding value activities, supporting and promoting suppliers lean implementation
			Suppliers involvement in production and product development systems	Partnership, supplier training, black box system, JIlt supply
	FLOW	Dense, regular, accurate and reliable flow	Dense flow , with high adding value time, clear pathways and communication	Mapping, work cell, one piece flow, multifunctional worker, automation, product lay-out, design for manufacturing
			Regular flow - paced by client / next process demand	Takt time, kanban, one piece flow
			Accurate and reliable flow	TQC, statistical process control, poka-yoke, jidoka, Total Productive Maintenance (TPM)
		Standard work	Work standardization	Work instructions, work content, cycle time and standard inventory definition
			Transparency	Visual management, 5S
			Low level decision	Delegation, training
	PULL		Pull versus push system	Kanban, takt time

52 (Picchi, 2001)

		JIT production and delivery	No overproduction, WIP (Work In Process) reduction	Kanban, standard inventory, FIFO:firt-in-first-out, small batches, one piece flow
			Demand smoothing : harmonizing market variations and production flexibility	Anticipation (Master plan), Peaks negotiation (Dealers system)
			Reflecting product variation in short periods of production	Heijunka, fast set-up, small batches
		Flexible resources	Information flexibility	Flexible information systems
			Equipment flexibility	Fast set-up, low cost automation, redundant equipment
			Workers flexibility	Multi-skill training, work cell
	PERFECTION	Learning	Fast problem detection	No buffer, no stock, kanban, small batches, one piece flow, first-in-first-out (FIFO), visual management, 5S, decision in operator level
			Fast problem solving in lower level and solution retention	Empowerment, teamwork, Quality Control Circles (QCC), 5 Whys, quality tools, kaizen
			Evolutionary learning	Kaikaku (dramatic changes), benchmarking
		Common focus	Leadership and strategy	Strategic planning, Policy deployment, Hoshin management, managers in workplace
			Structure	Teamwork, hierarchy levels reduction, cross functional structure
			Client and production focus diffusion	Training, day by day coaching, leadership example
			Human respect	Laying off as the last resort, Job system, work meaning enrichment, participation, empowerment, recognition, ergonomy, safety
			Total employee involvement	Suggestion system, QCC, kaizen, job system, training system
			Total system diffusion	Techniques standardization, simplicity in communication, system and techniques application in all processes and in whole company

CHAPTER 3: RESEARCH METHODOLOGY

This chapters deals with the methodology “Content analyses” used for the research. The objective of this thesis is to structurally analyze lean construction research development to define trends and examining the compliance of lean construction studies towards Toyota production system. Relevance of content analysis will be described in following sections and step-by-step procedure to conduct content analysis followed by reliability and validity of the method. Research implications are stated at the end of this chapter. This chapter will also cover creation of each category for analysis and brief description.

3.1. Content analysis

The research method used here to carry out the analysis is Content Analysis. Content Analysis is a common approach to analyse the documents. The document can be a newspaper article, a book, magazine, letter or any other type of written document. It is qualitative study which gives quantitative analysis of the content of the document. It can be defined in various ways, as defined by Krippendorff[53], content analysis is a research technique for making replicable and valid inferences from data to their context', while perhaps over-inclusive in not making clear that we are dealing with certain kinds of data (those coming from documents of various kinds), does have the feature stressing the relationship between content and context. This context includes the purpose of the document as well as institutional, social and cultural aspects. It also emphasizes that reliability and validity are central concerns in content analysis[54].
This method can also be used for non-written form of documents like films, photographs comics and cartoons with different approach than written form[54].

Steps to carry out content analysis[55],

1. Start with a research question.
2. Decide on a sampling strategy.
3. Define the recording unit.
4. Construct categories for analysis.
5. Test the code on samples of text and assess reliability.
6. Carry out the analysis.

Advantages of Content Analysis over other data generating and analysis techniques based on Weber[56],

- Documents of various kinds exist over extended periods of time, cultural indicators generated from such series constitute reliable data that may span even for centuries.

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[53] (Krippendorff, 1980)
[54] (Krippendorff, 1980) in (Robson, 2002, p. 348)
[55] (Robson, 2002, pp. 352-357)
[56] (Weber, 1990)

- Comparing to interview techniques, Content analysis yields unobtrusive measures in which neither the sender nor the receiver of the message is aware that it is being analysed. Hence, there is little danger that the act of measurement itself will act as a force for change that confounds the data.
- Content analysis studies can utilize both qualitative and quantitative operations within literature, thus it combines what are thought to be antithetical modes of analysis

Application of content analysis on this study is described below based on the steps mentioned above.

3.1.1. Start with a research question

This study was started with a main objective of analysing lean construction literature and its development through time from Toyota Production System (TPS) which is origin of lean principles[9]. From this objective following research questions can be derived,

1. Which Principle of TPS have been mostly considered under researches?
2. What research methods were mainly used?
3. What is the contribution of different countries in research in last year?
4. What are the key areas or problem in areas that requires further research?

3.1.2. Decide on a sampling strategy

It is usually necessary to reduce your task to manageable dimensions by sampling from the population of interest[55]. Data for the research was collected from the conference papers published in the International Group for Lean Construction (IGLC) since this conference represents the state of the art of Lean Construction research work and its implementation. It combines most researches in lean construction from all around the world covering many sectors of construction industry like Design management, Procurement and Contracting, Supply chain management etc.

The focus of this study was all the conference papers published in year 2016 which are in total 123 research papers.

3.1.3. Define the recording unit

Content analysis can be applied on a whole population of documents or a part of the sample depending on the interpretation of the investigator. In content analysis three sampling populations exist[55]: communication sources, document sampling, and texts within documents.

In this study, all papers were considered as they all falls under lean construction which is focus of the study instead of selecting keywords as a recording unit specified in the abstract by author.

3.1.4. Construct categories for analysis

There are many categories that can be used for content analysis. Robson[57] classifies these categories as follows,

Subject matter: What is it about?
Direction: How is it treated, e.g. favourably or not?
Values: What values are revealed?
Goals: What goals or intentions are revealed?
Methods: What methods are used to achieve these intentions?
Traits: What are the characteristics used in description?
Actors: Who is represented as carrying out the actions referred to?
Authority: In whose name are statements made?
Location: Where does the action take place?
Conflict: What are the sources and levels of conflict?
Endings: In what way are conflicts resolved (e.g. happily)?

As with structured observation systems, it is highly recommended that these categories are exhaustive and mutually exclusive[57]. The former ensures that everything relevant to the study can be categorized (even if you must create a 'dump' category for things that you don't know how to deal with). The latter means that anything to be analysed can be categorized in one way only; if it is categorized in one particular way, it can't also be categorized as something else[57].

[57] (Robson, 2002)

In this study, categories for analysis were constructed based on the criteria mentioned above by Robson with keeping the main objectives of study in mind. These categories are described comprehensively in the following section.

1. **Countries**

   This category gives the location of the primary author who conducted the study or the location where the case study was performed. In most cases both locations are similar, where there is different, the location of the author or the institute with which the author associated was considered.

2. **Stage of Construction**

   This category represents the construction stage that focused in the study to draw the conclusions. It is divided mainly in three stages;

   - **Preconstruction** includes planning, surveying, designing, procurement, tendering, permit planning and all other works that is required to be finished before executing the construction work.
   - **Construction stage** include execution of work on site and all supported activities like monitoring, controlling and management.
   - **Post-construction stage** includes Inspection work, Permit and licencing for usage after completion of the construction phase.
   - **Throughout** construction process classifies the studies which considers overall process rather than focusing on particular stage and gives general idea about the implication of results on total construction process.

3. **Constrain**

   As defined by Olsen[58] "Project management is the application of a collection of tools and techniques (such as the CPM and matrix organization) to direct the use of diverse resources toward the accomplishment of a unique, complex, one-time task within time, cost and quality constraints. Each task requires a particular mix of these tools and techniques structured to fit the task environment, and life cycle (from conception to completion) of the task". Construction Management as defined by Claugh and Sears "The judicious allocation of resources to complete a project at budget, on time, and at desired quality". All studies directly or indirectly affect the main there constrains of time, cost and quality. Since Construction management is about balancing Cost, time and Quality, All the

[58] (Olsen, 1971)

research has been categorised according to most weighted attributes among the three. So, the studies were classified according to the constrain focused in the paper. In most of the studies, no specific constrains was directly affected, those are classified with “All” Category which means the research affects all these attributes.

4. Categories of construction

Construction categories are classified according the type of works mentioned in the studies. Based on Eurostat[59], main two categories are building and civil engineering works. These two are further classified as described below.

Building constructions are roofed constructions which can be used separately, have been built for permanent purposes, can be entered by persons and are suitable or intended for protecting persons, animals or objects[59].

Heavy constructions are civil engineering works which are not building like power plants, industrial plants, chemical plants etc.

Infrastructural works includes Highways, Roads, Railways and Bridges, tunnels, subways, harbours, dams and other waterworks.

Multidisciplinary discuss more than one type of construction like hospital building and industrial plant in single study.

Re- construction work describes the studies related to re-construction and renovation of existing structures.

General construction includes the studies which are not focused on particular type of construction. The study concentrates on process or operation regardless of type of construction for example work flow process, organisational planning, controlling or collaboration of stakeholders.

5. Sub-categories of construction

Here the categories are further classified according to use of the structure. Constructions used or designed for several purposes (e.g. a combined residential, hotel and office building) are to be assigned to one classification item, according to the main use[59].

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[59] (Eurostat, 1997)

Buildings are further categorised into Commercial (Hotel, Offices, Cafeteria and shopping centres), Educational institute (Universities, Schools), Residential, Hospital, Industrial (iron ore extractors, Oil Rig, Ship yard), High-rise, Existing buildings, Public projects, External facades etc.

Infrastructural works are mostly transportation works as mentioned earlier in categories and one study in ramp construction.

Ship cabin is special category which studies the construction of cabins inside a cruise ship.

MEP works, prefabricate works, ceramic works are classified from the **General construction category.** The rest are named Uncategorised as they are studies related to General works which does not specify any usage or type of construction.

6. **TPS Principle**

   14 TPS principles are classified in main four TPS categories; Philosophy, Process, People and Partners, Problem Solving. The other categories are Non-TPS category which does not follow TPS framework by Liker[7]. So, studies in Non-TPS category are separated by their context or subject-matter. The studies that neither belong to Lean construction nor to TPS framework are put as Outliers category.

7. **Context/Subject matter**

   In this category, all Non-TPS studies are further categorised into new 15 categories according to their subject matter, from which author derives conclusions. A list of all categories is described in the table 5 below,

Table 5: Clarification of Research Categories[60].

Research Categories	Definitions
Philosophy	TPS Category
Process	TPS Category
People and Partners	TPS Category
Problem Solving	TPS Category
Contracting and procurement	To support Lean delivery from beginning of the project.
Benchmarking	A tool to measure quality by comparing and evaluating practice with best practice from construction and other industry.
BIM	Use of BIM and its aspect combined with Lean Principles.
Sustainable development	Use of sustainable methods and materials for Green development.
Simulation	Simulation of Lean principles by games to explain and measure benefits.
Design Management	Applying & integrating lean tools in pre-construction stage to for better management and performance by reduce waste in design.
Review & Evaluation	Review and Evaluation of available research methods & literature and its implementation.
Outlier	No relevance to TPS or Non-TPS categories (Total 8 studies).
Safety	Safety related research in construction.
Behavioral study	A study about behavioral patterns of stakeholders.
Organizational structure	Review, modification or change in structure or strategy or power of organization.
Historic Preservation	Preservation of existing buildings of historical values.
Competencies	Skills and knowledge of employees engaged with project.
Collaboration	Partnership and teamwork from beginning with all stakeholders during whole project.
New theories	Development of new theories from other industries and new platforms. For example, use of Stigmergy, Filmmaking, Social networks.

60 Own tabulation.

8. Lean Principle

According to lean tool used for the study, all studies are classified respectively. There are some studies where more than one lean principle was used so those studies are separated with combination of lean principles. All lean tools are explained in section 2.6 of previous chapter.

9. Methodology

Research methods adopted by the author are categorized in this category. Various methodologies used in studies are briefly described below.

Literature review: Literature review is a process of identifying, interpreting and evaluating all available research relevant to particular research questions or ideas[61]. The studies which uses main method of research as literature review to derive new theory or confirm existing theory are categories in this column. It can be helpful to summarize limitation and advantages of particular method, identify the gaps in present research or provide background for future research works[61].
Case study: Case studies are conducted to understand and implement the theory in real life conditions. It answers the research questions with How? And Why? Since they are explanatory and can be explained by case or experiment[62]. All papers which uses the case study as a main method of research are classified in this category. They also can include literature part as a background as mentioned earlier. Case can be single or multiple and data collection method for the case study could be different.
Interview: interviews are useful for qualitative research and seeks the answers of research question based on interviewee's answers. Since it depends on the interpretation of answers, research work based on interviewer may require training. For this research, all studies with interview technique are categorized in this column.

[61] (Kitchenham , 2007)
[62] (Saunders, Lewis, & Thornhill, 2009)

Design Science Research: Design research involves the analysis of the use and performance of designed artefacts to understand, explain and very frequently to improve on the behaviour of aspects of Information Systems[63]. DSR finds new innovative solutions to the problems or achieve improvement.

Questionnaire Survey: traditional questionnaire surveys in the written form or online are being performed by the studies in this category.

Simulation: The Lean Construction Institute (LCI) uses simulations to explain lean concepts[64]. Simulations have played a crucial role in Lean construction (LC) by successfully demonstrating the practical implications of lean principles. According to Canizares[65] and Walters[66], the simulated game environment helps participants to comprehend real world scenarios, enabling students to understand more easily lean concepts and their application to construction industry processes. Studies with this method are classified in this column.

Action Research: “Action research aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework”[63]. According to this description AR can be used for both research and practice work at the same time. So, it its cyclical activity where researchers will improve their practice by implementing, evaluating and improving the results with trial and error concept.

Constructive Research Approach: This method aims to solve practical problems while creating an academically appreciated theoretical input. The solutions can be in form of processes or charts. The research process is in the steps: (1) selecting a practically relevant problem; (2) obtaining a comprehensive understanding of the study area; (3) designing one or more applicable solutions to the problem; (4) demonstrating the solution’s feasibility; (5) linking the results back to the theory and demonstrating their practical contribution; and (6) examining the general inability of the results[67]. There is one study, which followed this methodology.

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[63] (Iivari & Venable, 2009)
[64] (Verma, 2003)
[65] (Canizares, 1997)
[66] (Walters, Coalters, & Rasheed, 1997)
[67] (Pasian, 2015)

Computational Case study: one studies was categories in this column because Computational techniques are used to calculate production makespan and penalty costs with different buffer sizes. The aim was to examine the impact of buffer size between stations on production makespan and costs[68].

Combined: In some studies, more than one research methods were used, those classified in this category. Author can either use a single data collection technique and corresponding analysis procedures (mono method) or use more than one data collection technique and analysis procedures to answer your research question (multiple methods)[62]. For example, Case study and questionnaire, case study and interview or design science research and interview etc.

10. **Advantages**

    This category enlists the possible advantages of the result or conclusion from the study.

11. **Limitation/ Barriers**

    This category gives idea about the limitation or barrier to implement derived results in real conditions. So that it can be noticed by future researchers for further improvement in result or process to make it more feasible. This category strictly records the limitations as mentioned by the author of respective research in paper. There is no personal evaluation or opinion on the study involved.

12. **Conclusion**

    This category gives summary of conclusion of all research studies in brief.

13. **Remarks/Future scope**

    Here remarks or notes from the author are mentioned, if any available or probable future research suggested by author in the field is listed in this column.

3.1.5. Test the code on samples of text and assess reliability

This is the best test of the clarity and lack of ambiguity of defined categories[57]. When the scheme appears workable, tests of reliability should be made. If the reliability is low, further practice is necessary, and it may also be necessary to revise the coding rules. The process should be repeated until the reliability is acceptable. If computer coding has been used, it is necessary to check for errors in computer procedures[57].

[68] (Ko, 2016)

Here coding was completed on entire text documents instead of the keywords based on the interpretation of the author. The code scheme introduced as follows,

- All TPS categories were considered mutually exclusive. A text or study belongs to only a single category of four TPS categories or the other non-TPS categories[69].
- To classify a category, range of categories was determined. The range was depending on the Basic 14 TPS principle mentioned by Liker[9]. The main four TPS categories were assigned according to principle used in the given study paper. For example, if the study follows pull system it will categorised as Process categories and if study follows long term thinking it will come under Philosophy category. This coding is represented in figure below.

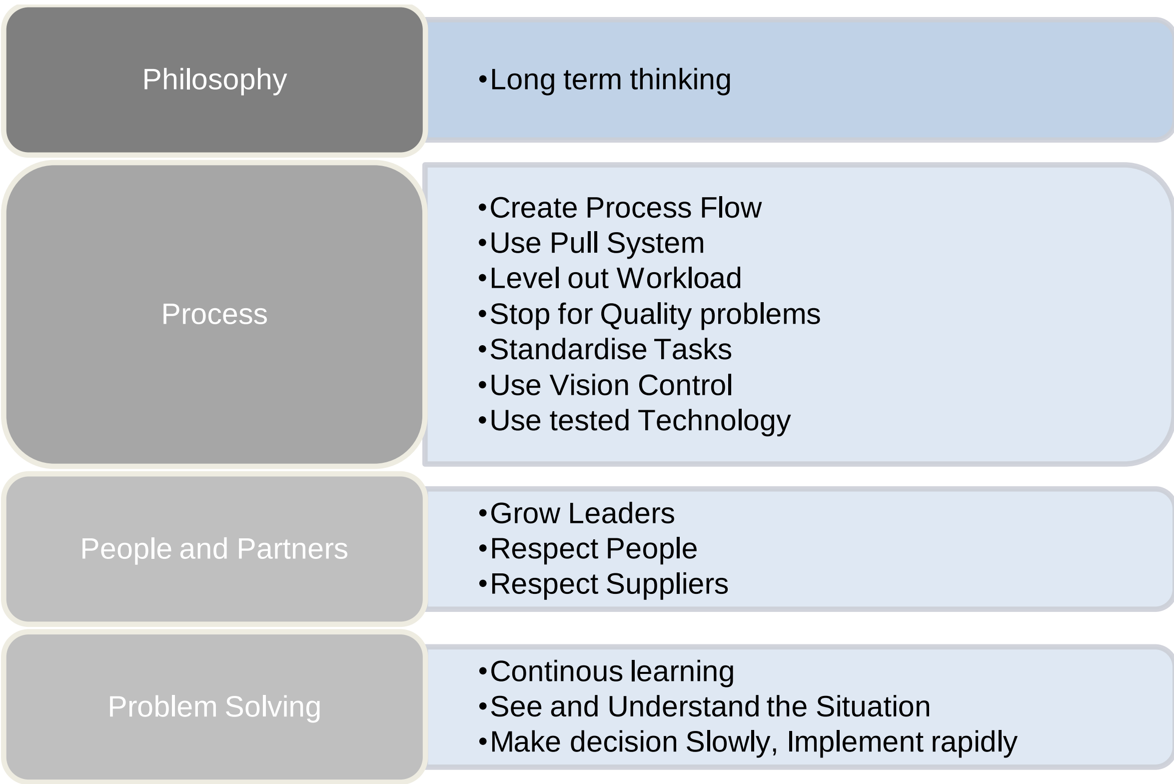

Figure 6: Priciples considered to decide the category of study[7]

- The Non-TPS categories were classified according to their context and those studies which does not fall under TPS or Non-TPS considered as Outliers as mentioned earlier in section 3.1.4.

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[69] (Jacobs G. F., 2010)

3.1.5.1. Reliability

Reliability gives assurance that results of the study can be duplicated. Here Reliability can be descried in following two terms as mentioned by Stemler[70].

Stability or intra-rater reliability: Can the same coder get the same results try after try?

Reproducibility or inter-rater reliability: Do coding schemes lead to the same text being coded in the same category by different people?

Several coefficients for measuring agreement are available, specialized for particular kinds of data. Krippendorff's α is the most general agreement measure with appropriate reliability interpretations in content analysis[71].

$$\alpha = 1 - \frac{D_o}{D_e},$$

α can be derived by subtracting ratio of observed disagreement (D_0) to possible disagreement when chance prevail (D_e) from one[72].

Data is reliable when α is more than 0.80[71]. To establish the reliability of data, reliability data need to be representative of the population of data whose reliability is in question. As a rule of thumb, each category of units should occur often enough to yield at least five agreements by chance[73]. 10% of the total studied research papers can satisfy this requirement.

So, for **Intra-rater reliability** 10% (12) randomly selected studies were re-analysed by the author in same manner. Coefficient α was calculated 0.92 from this analysis according to the above-mentioned formula of Krippendorff.

For **Inter-rater reliability** 10% randomly selected studies were re-analysed by the external inter-rater who is not associated with this study but have similar interest and research background. By this analysis, Coefficient α was calculated 0.83 which is higher than minimum require to consider the data reliable.

The intra-rater test table can be seen in appendix B & inter-rated test table is presented in appendix C.

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[70] (Stemler, 2001)
[71] (Krippendorff K. , 2004, p. 242)
[72] (Krippendorff K. , 2004, p. 222)
[73] (Krippendorff K. , 2004, p. 239)

3.1.5.2. Validity

Validity is that quality of research results which leads us to accept them as true. A content analysis is valid if the inferences drawn from the available texts withstand the test of independently available evidence, of new observations or competing interpretations[74].

The interpretations were generalized to lean construction research in this study since only IGLC conference papers were considered for this study.

Trustworthiness relates to this study and causes it to be ”worth paying attention to” because the data comes directly from researchers in the field[75]. All studies were peer reviewed by industrial expert before being accepted in IGLC which proves their credibility of the results. So, it can be used in the content analysis for the purpose of this study.

3.1.6. Carry out the analysis

Analysis is divided into two types: exploratory and confirmatory. Exploratory analysis explores the data, trying to find out what they tell you and confirmatory analysis seeks to establish whether you have actually got what you expected to find[76].

For this study, analysis was carried out to find out research trends on lean construction studies from IGLC database which uses both exploratory and confirmatory analysis types. In exploratory stage categories were created as mentioned in step 1 and step 2. In Confirmatory analysis understanding of widely used research areas, construction types and lean principles developed through charts as shown in step 3. It also compares the lean construction studies with TPS principles to identify its compliance with them.

Analysis follows following procedure,

Step 1: All studies were recorded in Microsoft Excel with different columns named after constructed categories for analysis.

[74] (Krippendorff K. , 2004, p. 313)
[75] (Lincoln & Guba, 1985) in (Jacobs G. F., 2010)
[76] (Robson, 2002, p. 399)

Step 2: Each study was assigned a category manually with respect to its content like location, focused stage of construction, type of construction, TPS category, Non TPS category, used lean principle, used methodology for the study etc.

Publicati	Author	Title	Abstract Note	Country	Stage	Constrain	Category	Sub category	TPS Principle	Context	Lean principle
2016	Wu, Peng; Wang, Xiangy	A Critical Review of the Factors Affecting the	Due to the rising recognition of sustainable	Australia	Construction	Cost	General constructi on	Uncategorized	Other	Sustainable development	Waste reduction
2016	Dallasega, Patrick; Marcl	A Decentralized and Pull-Based Control Loop for On-	Engineer-to-Order (ETO) process chain	Italy	Pre-Construction	Time	Building	External facades	Process	Supply chain mangement	Just-in-time
2016	Khan, Sheriz; Tzortzopou	A Framework for Evaluating an Action Research	There is no convention for evaluating	UK	Pre-Construction	Cost	Building	Commercial	Other	Design Management	Last planner system
2016	Emdanat, Samir; Linnik, I	A Framework for Integrating Takt Planning, Last	This paper proposes a framework for	USA	Construction	Cost	Building	Hospital	Philosophy	Production plannig and controlling	LPS +Takt time
2016	Pérez, Cristina T.; Fernan	A Literature Review on 4d Bim for Logistics Operations	Planning the logistic operations and	Brazil	pre-Construction	Time	General constructi on	Uncategorized	Process	Supply chain mangement	5S

Figure 7: Screenshot from Excel sheet showing categories for analysis

Step 3: After recording all 123 studies in Microsoft Excel, with the help of Pivot Table tool, various charts from various categories generated to represent the result of the analysis graphically. Combination of one column with another gives different perspective. With this data tables many sides of the research could be unfolded by combining desirable columns.

Findings of this study will characterise some of the possible charts in chapter 4. Figure below shows a screenshot from Excel data sheet.

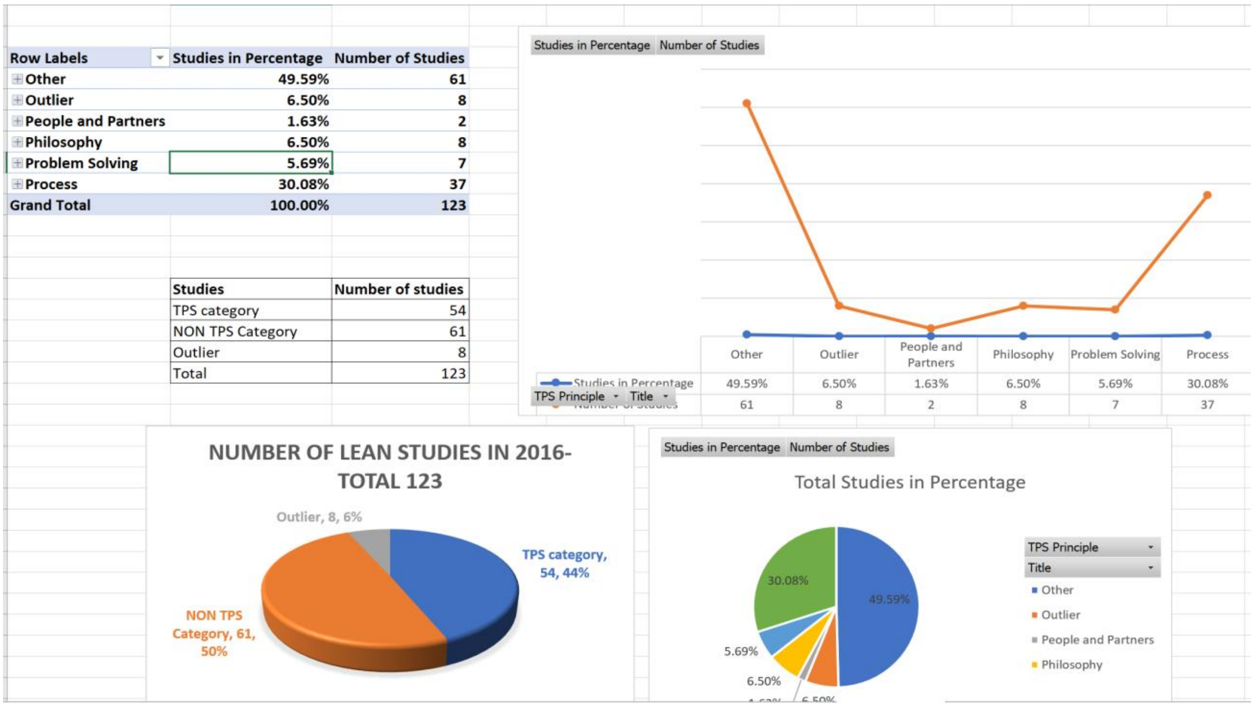

Figure 8: Screen shot from Excel sheet showing charts as a result of analysis

3.2. Research Implications

This result provides guidance to future researchers in Lean Construction about demanding research areas in construction and suggests not to limit their work for only particular sectors of construction. Results can also be used as a reference to avoid duplication of work which is already explored and to develop those works a step further.

Based on lean tool literature, professionals can review relevant tool's success or failure to apply it in industry. They can choose widely researched tool, or special tool relevant to their form of construction and type of organisation.

CHAPTER 4: FINDINGS

This chapter describes the results of analysis of lean construction research studies and its compliance towards TPS system. It will also answer four research questions raised for the purpose of research. The objective of this thesis is to structurally analyze how lean research has developed through years. Also, to find out how these researches are focusing on basic lean principles. The result of analysis is represented in form of charts and description. It will guide researchers to focus on least developed area in lean construction for further research.

4.1. Significance of TPS principles for lean construction research

To successfully implement lean thinking in any construction system TPS principles must be followed. TPS system is categorized in four main categories namely 1) Long Term Philosophy which includes one principle of long term thinking 2) The Right Process will produce the right results which includes seven principles 3) Add Value to the Organization by developing your People which follows three principles 4) Continuously solving Root Problems Drives Organizational Learning which consist three principles.[77]

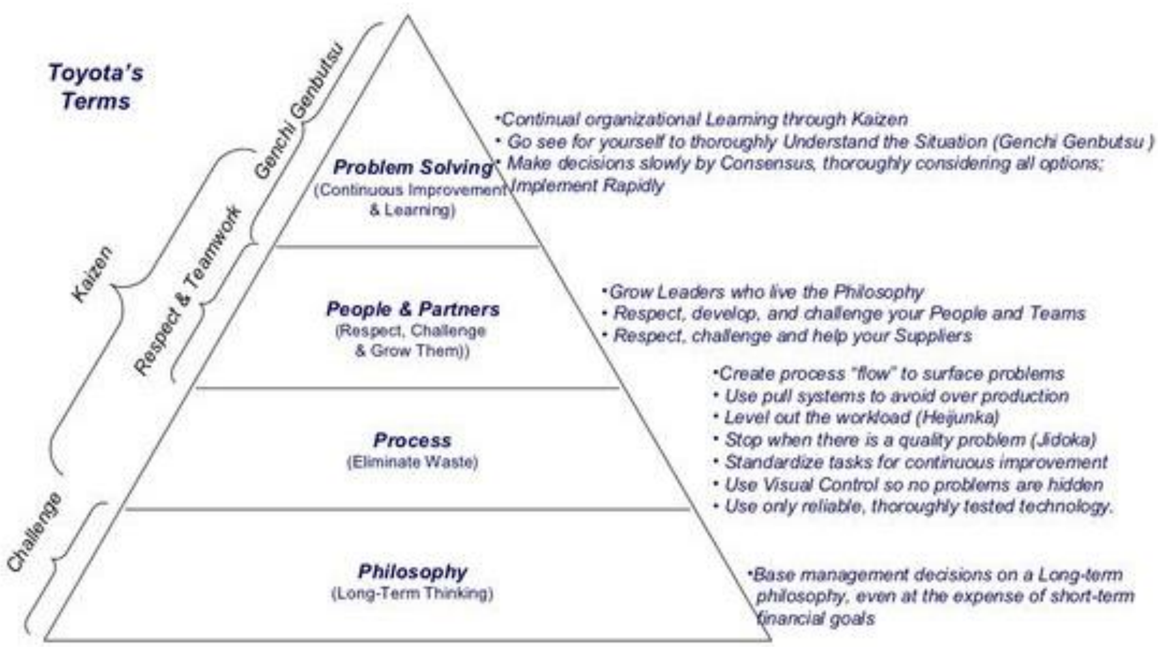

Figure 9 Implementation of Lean by "The Toyota Way"[9]

All 14 principles are described in section 4.2 below.

With the help of these principles lean tools have been developed as mentioned in section 2.6.

[77] (Liker , 2004, p. 52)

4.2. Building Blocks of Toyota: TPS principles

4.2.1. Long Term Philosophy

Principle 1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals[78]*.*

This principle is about having a motivation that suppress short term decision making. Change company's organization according to achieve bigger goal apart from money and develop common purpose throughout company which is foundation for every other principles. To produce value for customer and society should be the main focus and starting objective of every activities.

4.2.2. The Right Process

Principle 2. Create continuous process flow to bring problems to the surface[78]*.*

Design process to produce continuous flow, remove anything that needs waiting time to start work to achieve add value. Continues flow of information and material should connect all engaged people and process to identify problems immediately. Flow should be obvious in organizational culture to for continuous improvement.

Principle 3. Use "pull" systems to avoid overproduction[80][78]*.*

Keeping customer needs in mind, material supply should be designed to avoid disturbance in production process. Minimize work-in-progress and storage of material on basis of what customer buys. Check the daily reports to avoid waste producing activities and avoid depending on only planned schedule.

Principle 4. Level out the workload (heijunka)[78]*.*

Elimination of waste is most important to implement lean in order to not waste resources of people and material. Leveling out the workload in all process is better that start work after stop as in batch system.

[78] (Liker , 2004, pp. 51-58)

Principle 5. Build a culture of stopping to fix problems, to get quality right the first time[78].
Quality assurance is important for customer satisfaction, building automatic system to verify quality and problems with that, and stop for solution improves value. Visual alert system to provide assistance to machine or people lays foundation for quality (Jidoka). To solve problems, organizational system should be ready with support system and countermeasures. Productivity can be improved by delivering quality right from the first time by integrating cultural change.

Principle 6. Standardized tasks are the foundation for continuous improvement and employee empowerment[78].
To maintain regularity in output from the process use verified and stable methods in all process, which is base of pull and flow principle. Best practices up to certain point of time should be recorded to standardize current practices. Standards should be made in a way that is easy to pass on from person to person.

Principle 7. Use visual control so no problems are hidden[78].

Visual control can be used to regulate the working condition, if it's standard or deviating from the requirements. It should be designed in simple way on the working place to support the flow and pull. Documentation should be as small as possible in size, ideally, one page.

Principle 8. Use only reliable, thoroughly tested technology that serves your people and processes[78].

Technology should be used to support people in the process not to replace people. New technology is hard to relay on and to standardize. In case of use, testing of that technology is important. Technology interrupting the flow or culture of working should be avoided. Moreover, people should be motivated to use new and tested technology, if it improves the overall flow in testing.

4.2.3. People and Partners

Principle 9. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others[78].

Leaders should be created within the company instead of hiring from another company. Their job should reflect company's philosophy and principles and leader must know every details of routine work to teach it further.

Principle 10. Develop exceptional people and teams who follow your company's philosophy[78].

Strong culture in company should be developed to sustain company's value and principles for long period of time. Training to exceptional people and team should be provided to achieve exceptional results. Team work should be promoted, and working culture in team should be continuously taught to the individuals.

Principle 11. Respect your extended network of partners and suppliers by challenging them and helping them improve[78].

Each and every partner and supplier should be treated with respect to expand business. To show them your value towards them, give opportunity to your outside partners for challenging targets and assist them to overcome this challenge.

4.2.4. Problem Solving

Principle 12. Go and see for yourself to thoroughly understand the situation (genchi genbutsu)[78].

Problem solving should be handled personally by going to the location where problem occurs instead of reacting according to computer. React based on personally verified data source. This is also true for upper level employees to understand situation better.

Principle 13. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly[78].

Do not focus on single option without considering all the available alternatives. Discuss pros and cons with all engaged person, which is called 'Nemawashi' to collect their views and agree upon single view. This process is time consuming but very effective to generate different solutions and after decision easy to implement.

Principle 14. Become a learning organization through relentless reflection (hansei) and continuous improvement (kaizen)[78]*.*

Continuous improvement is required after setting a process to identify root cause of problems and possible solutions. Process should be designed with less inventories to make visible the time and resource waste and afterwards assign improvement to remove it. Organization knowledge should be protected by steady workforces, promotion and succession systems.

Toyota invented lean production (also known as the Toyota Production System or TPS)[9] based on these principles. Keeping these 14 principles in center, all 123 IGLC studies were analyzed to identify how lean construction research has developed through time and how many studies follows these principles and how many researches have been diverged from this basic TPS principles. Those which does not follow TPS, are categorized as a new category depending on its context and represented as Non-TPS categories.

Figure 8 gives the distribution of all studies published in IGLC for year 2016.

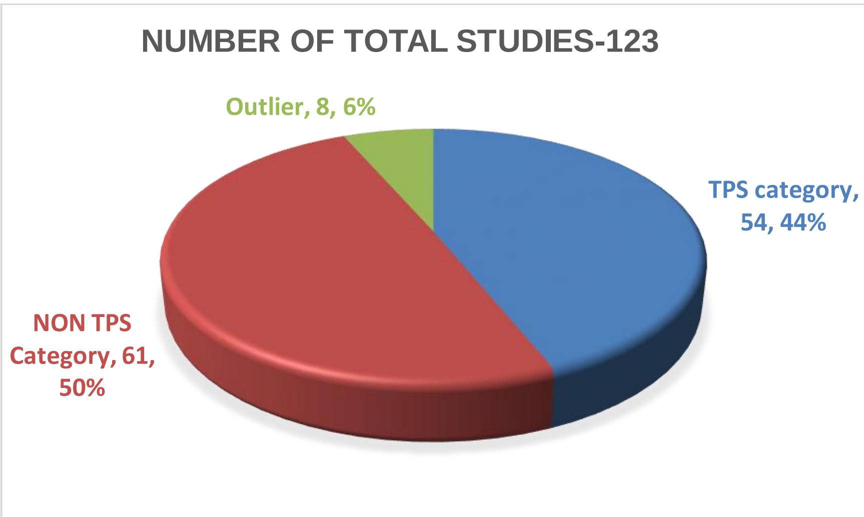

Figure 10: Breakdown of total 123 studies published in IGLC 2016

Out of total 123 studies 54% (54) studies comply with the TPS framework suggested by Liker[7]. Among the rest studies are 50% Non-TPS studies which are classified into new categories according to their context. 9 % (8) studies were classified as outlier because they neither comply with TPS framework nor uses lean tool. From total 123 studies 94% studies conducted utilized one of the above mentioned lean tools in section 2.6 for research. Further classification of lean tools utilized is described as an answer to question 1. The significance of these classification is in identifying the tools which lags behind in development. Lean construction research in future can diversify on basis of this study of past usage.

4.3. Research question Answers

4.3.1. Which principle of TPS have been mostly considered under these researches?

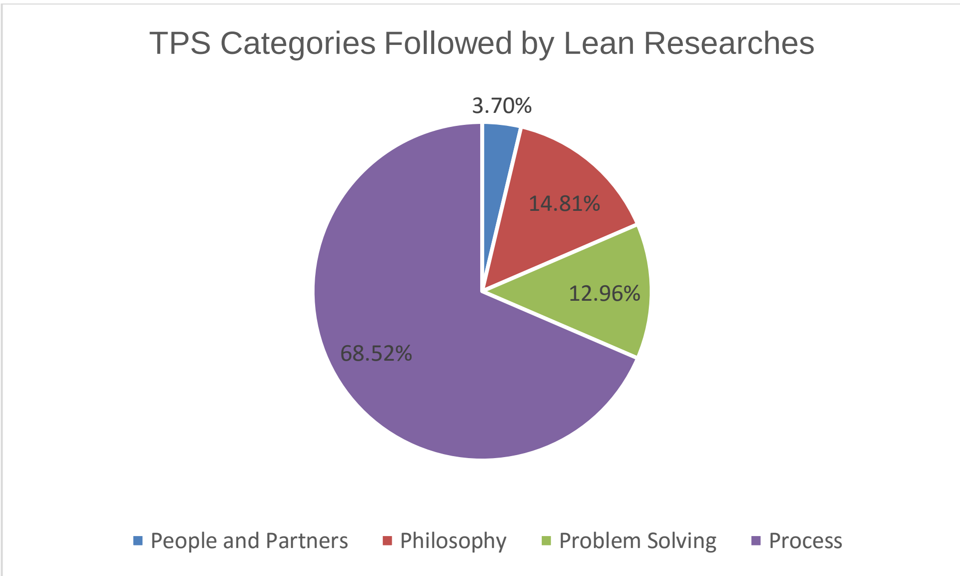

Figure 11: Breakdown of four TPS categories Considered by researchers

Process is constant procedures that take place throughout the project. As the chart in Figure 11 depicts, around 69% (37 studies) of total studies followed TPS framework are related to the ‘Process’ means to eliminate waste from the processes. Toyota put highest value in team members and tries best to listen them to integrate their ideas into planning process[9]. People and Partners is least researched principle with only around 4% (two studies). Philosophy in construction is associated with long-term thinking principle to outline strategies for long term goals. Problem solving deals with running operational performance and solving detected problems immediately. Studies followed philosophy and problem solving research are respectively 15% (8) and 13% (7).

Lean tools used in ‘Process’ category are shown in chart below. Last planner system and takt time is mostly considered lean tool to improve flows in process.

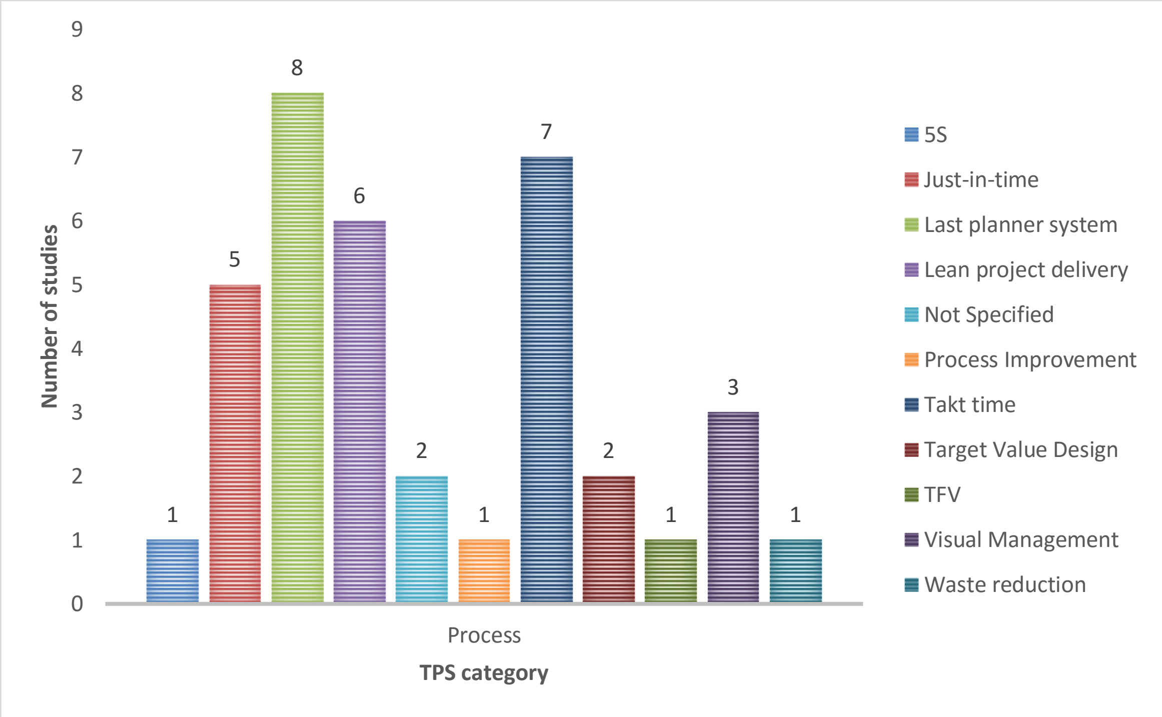

Figure 12: Lean tools used in TPS category 'Process'

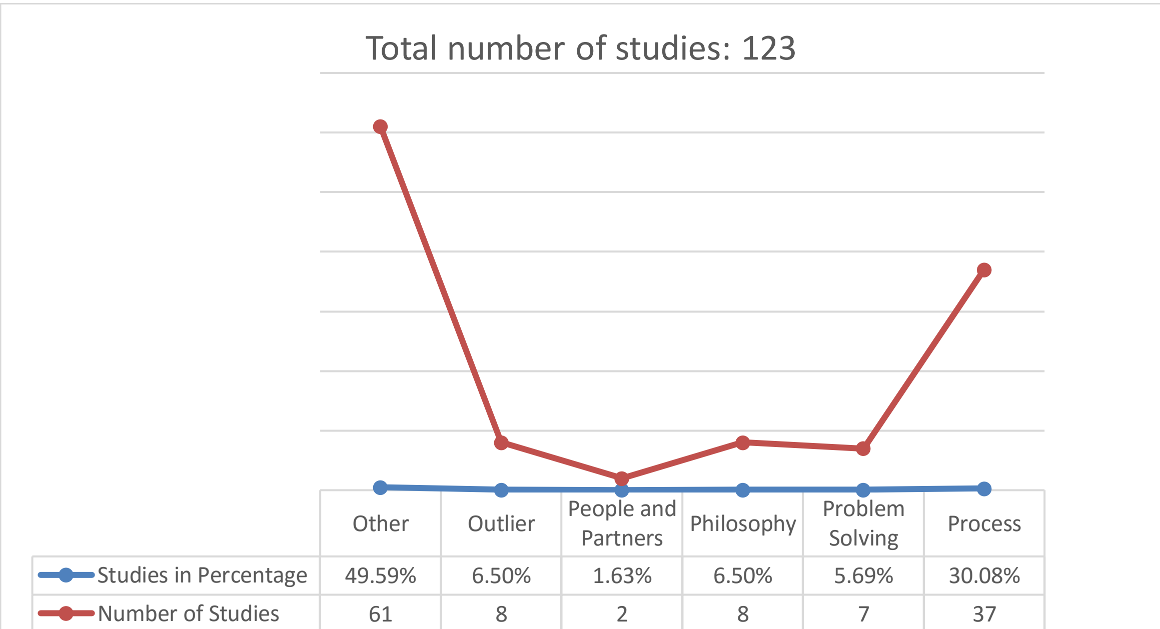

Figure 13: Trends of reseach categories in 2016

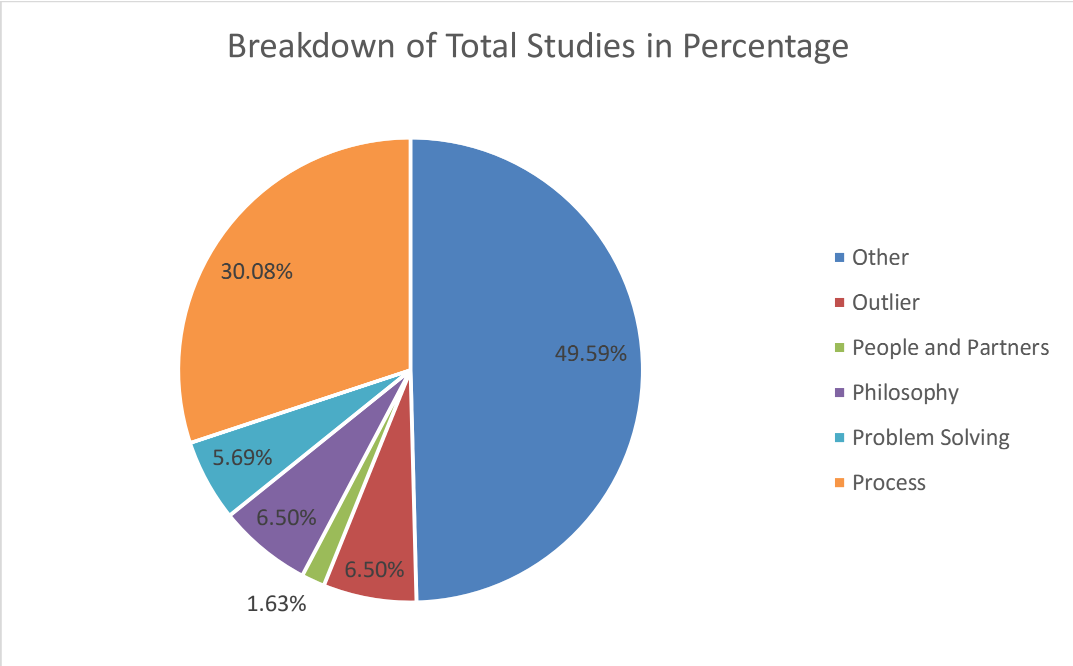

Figure 14: Breakdown of four TPS category with other (Non-TPS) categories

Figure 13 gives further breakdown as a percentage of total studies in year 2016 with four TPS principles Philosophy (6.5%), Process (30.1%), People and Partners (1.63%), Problem-solving (5.7%) reaveling trends of research. It can be seen that there are least studies are in People and Partner principle and the most studies are in Process which results from application of tools like Last Planner System, Lean Project Delivery system and Just-in-time technique as shown in figure 13. Problem solving category includes lean principles like 5s, Process Improvement, High-mix Low-volume. The other (Non-TPS) category includes 15 sub categories separated by their context as shown in Figure 15. Out of total 61 studies in 'Other' category, most research was conducted on BIM (17) followed by Design management (8). Permit planning, Preservation, collaboration, behavioral studies are very few, a study for each.

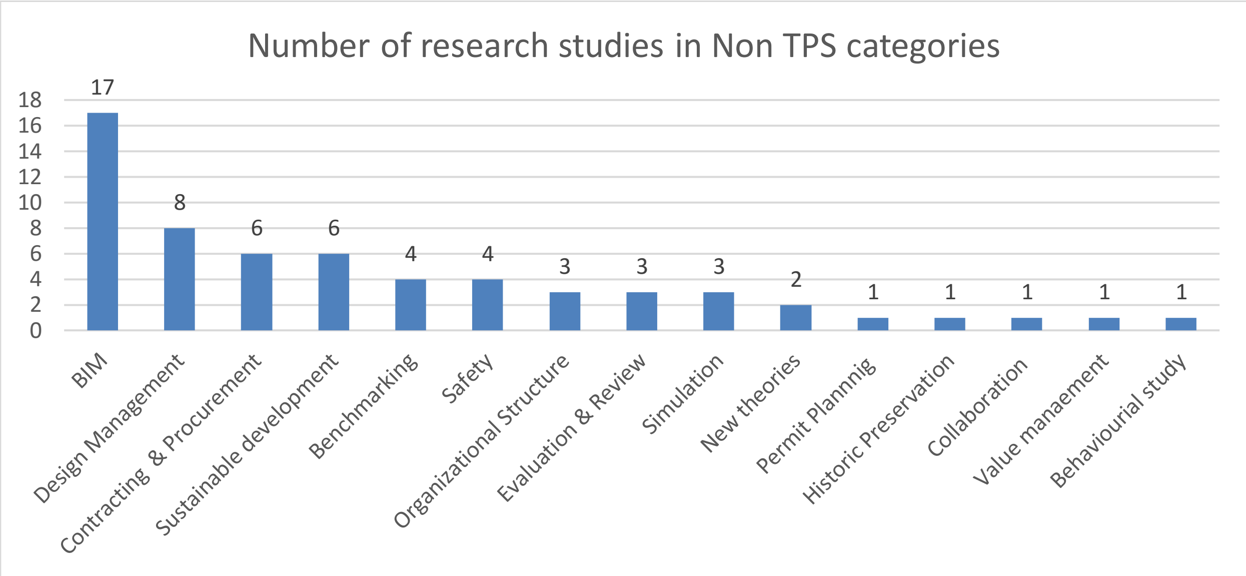

Figure 15: Breakdown of Non-TPS category according to context

Lean tools as covered in section 2.6 in chapter 2, considered under these four TPS principles are shown in Figure 16 below. Last planner system was used by all these TPS categories, it means utilization of last planner system completely follow TPS framework and it is widely used in Lean construction management.

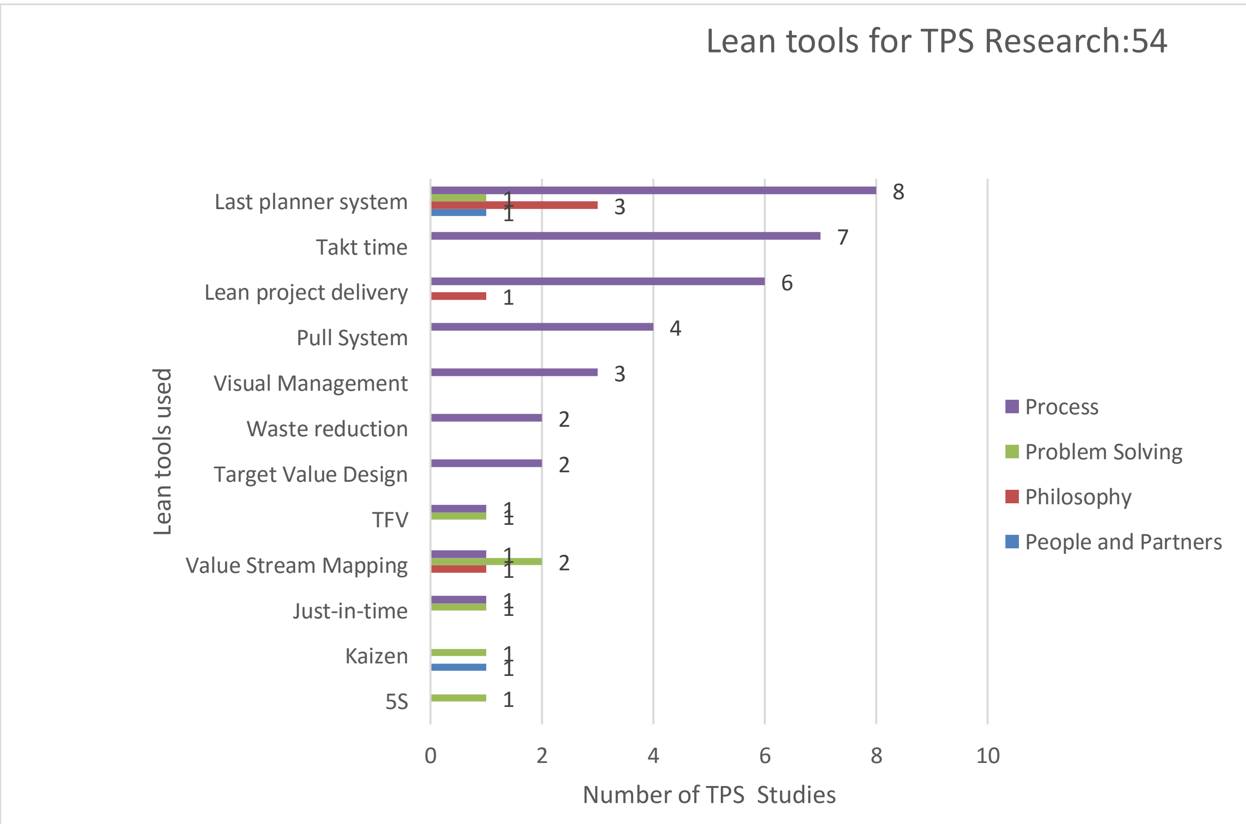

Figure 16: lean tools used in TPS categories research studies

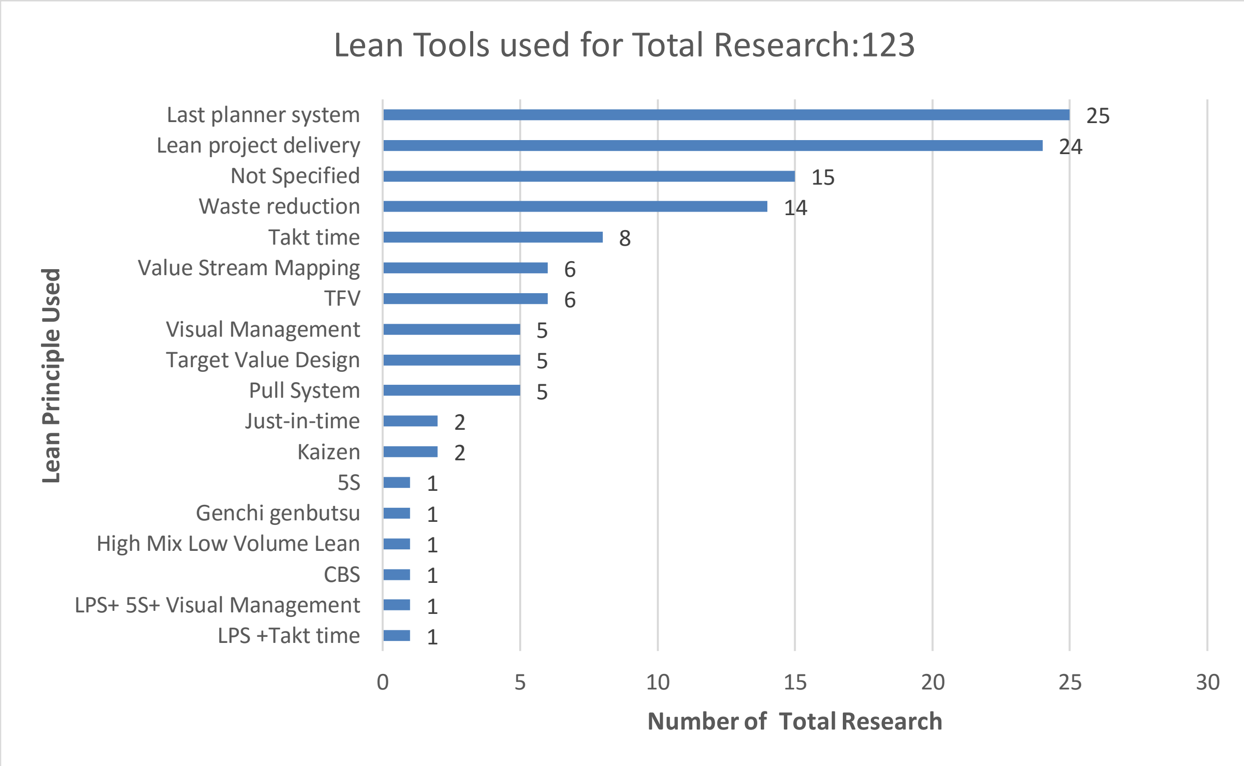

Figure 17: Lean tools used in all 123 studies

Figures 17 above shows the lean tools used for the total studies and that used in studies under TPS framework. Last Planner System seems to be most widely used lean tool for both the cases. Lean Project delivery and Takt time along with Pull system are then successor of the Last planner System. There are some studies which uses combination of more than one lean tools. In combitionation with other tools also the Last planner system is also combined mostly. All these tools are explained in section 2.6.

4.3.2. What research methods were mainly used?

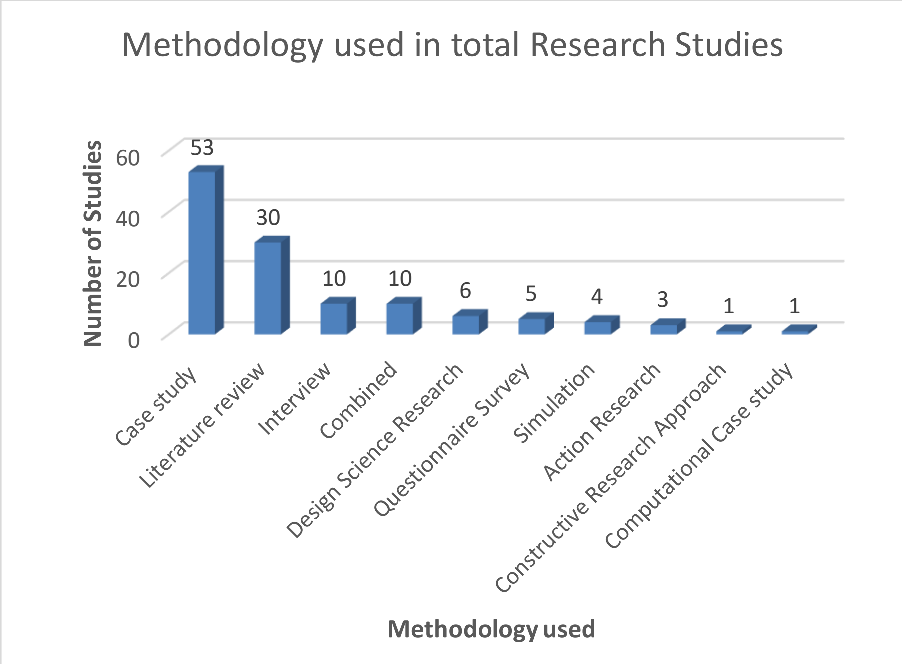

Figure 18: Researc methodologies used for research

Figure 18 shows all methods used for research in last year. There is single study with constructive research approach and computational case study methods. In combined method there is more than one methods were used. The other studies uses design science research, simulation, and action research. Case studies and Literature review are two methods widely used for research. All these methods are explained in brief in section 3.1.4. Construct category with subsection methodology.

Case study and literature methods are classified further with the area of focus in figure 19 below. From this chart readers can understand that in which areas these methods were adopted. Case study was helpful to applying lean with BIM and production planning. Whereas literature review was used more to evaluate the available materials and theories in lean construction. There are no literature studies available with focus in Benchmarking, behavioral study, contracting and procurement, permit planning and standardization which is necessary for deep understanding of the subject previous research in the field about the subject. On the other side there is no case studies to challenge the theories into practice with focus in historic preservation, simulation and value management research. Balance between both is important to maintain in any research field.

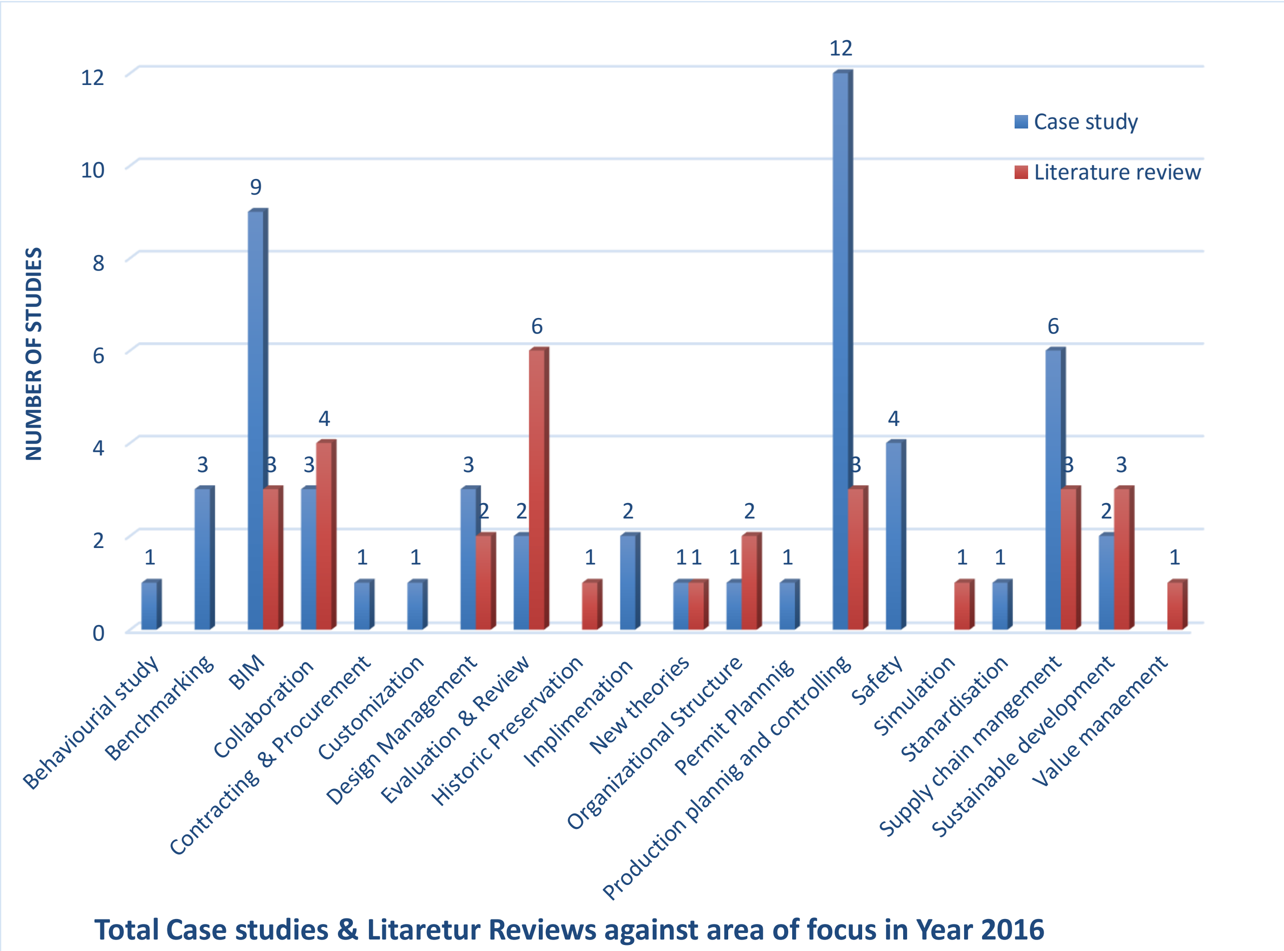

Figure 19: Total Case studies & Litaretur Reviews against area of focus in Year 2016

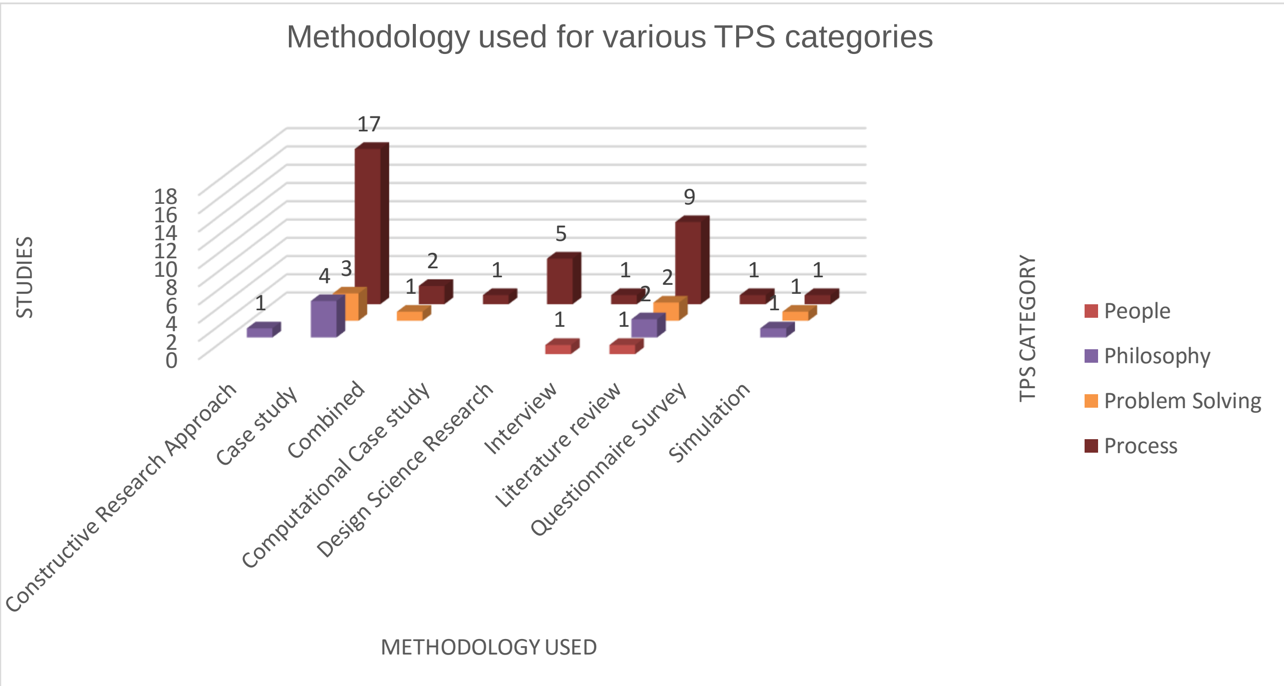

Figure 20: Methodologies used for studies under TPS categories

Figure 20 depicts the research methodology used in TPS based research works. Maximum number of studies were in process improvement and it was proved by case studies. People and partner related studies were conducted by interview and literature review. But these studies are only two in number so there is further need to conduct studies in this area.

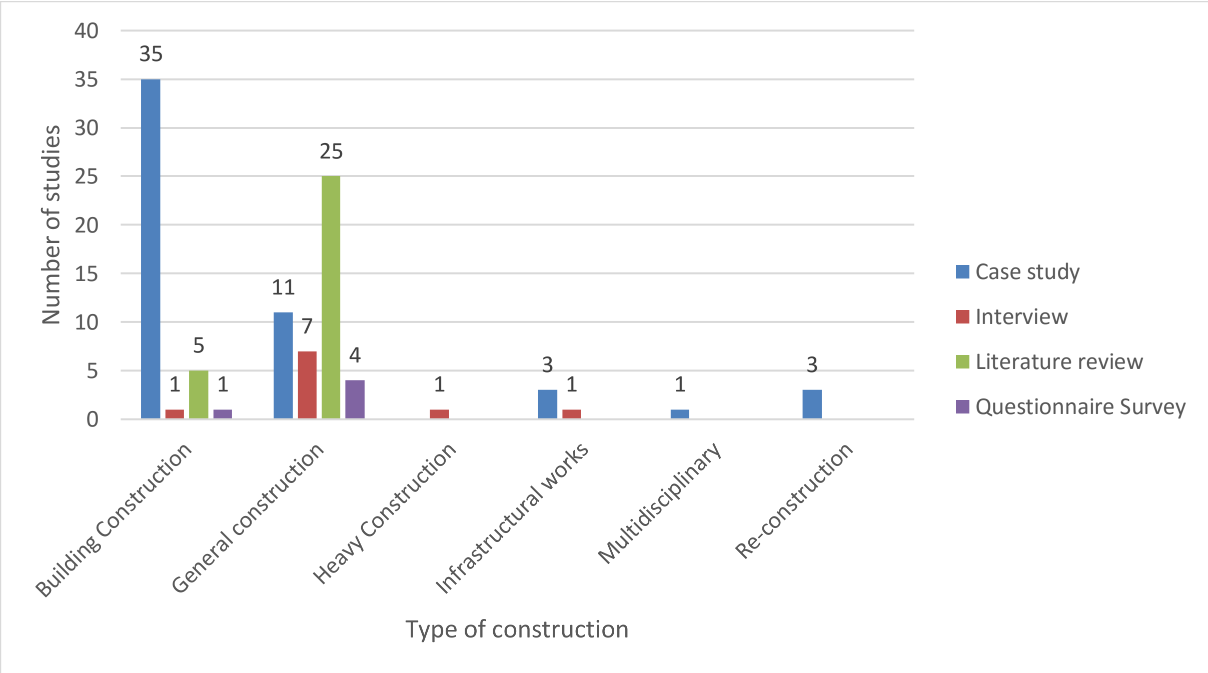

Figure 21: Methodologies used in different type of construction in 2016

Chart above shows main four methodologies used in different type of construction. It shows least research in heavy construction works, infrastructural works and re-construction. That suggest to conduct literature review as starting point to find current state of art in this sector and then develop new theory based on requirement. That will drive interest for case studies in these sectors to prove the new developed theory.
Chart below shows lean tools breakdown against different methodologies.

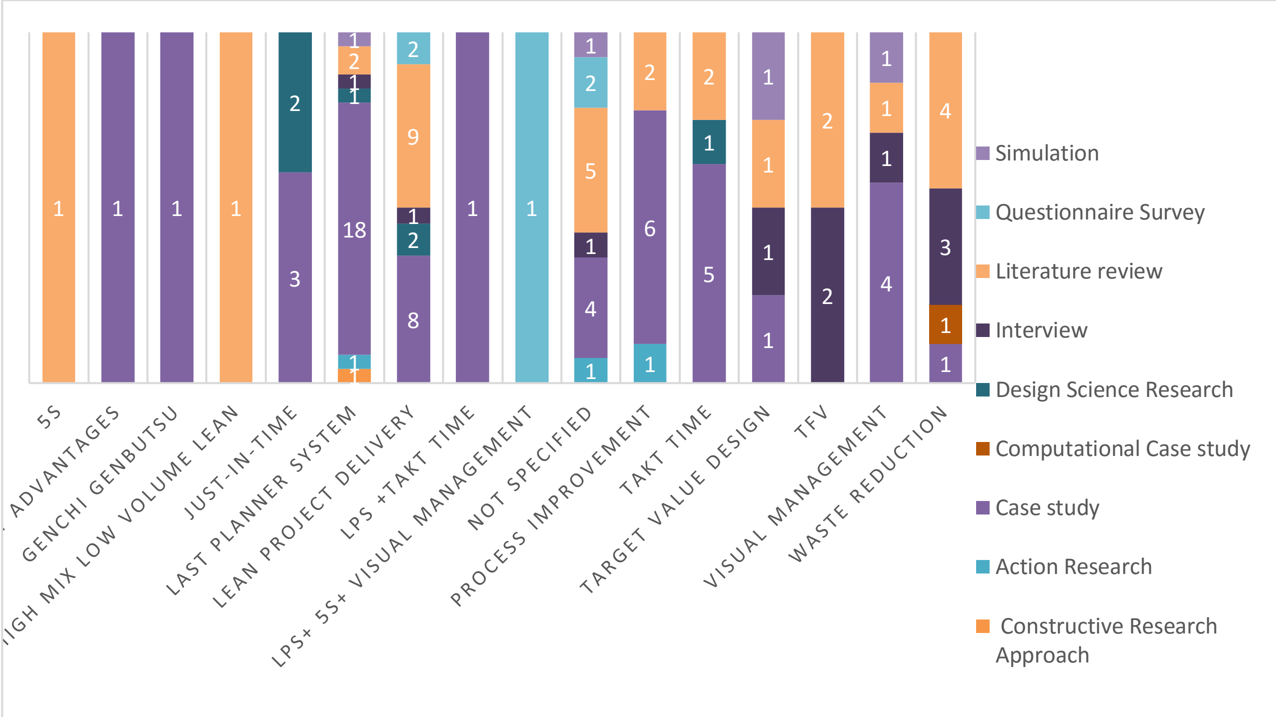

Figure 22: Lean tools used in different research methodologies

4.3.3. What is the contribution of different countries in research in last year?

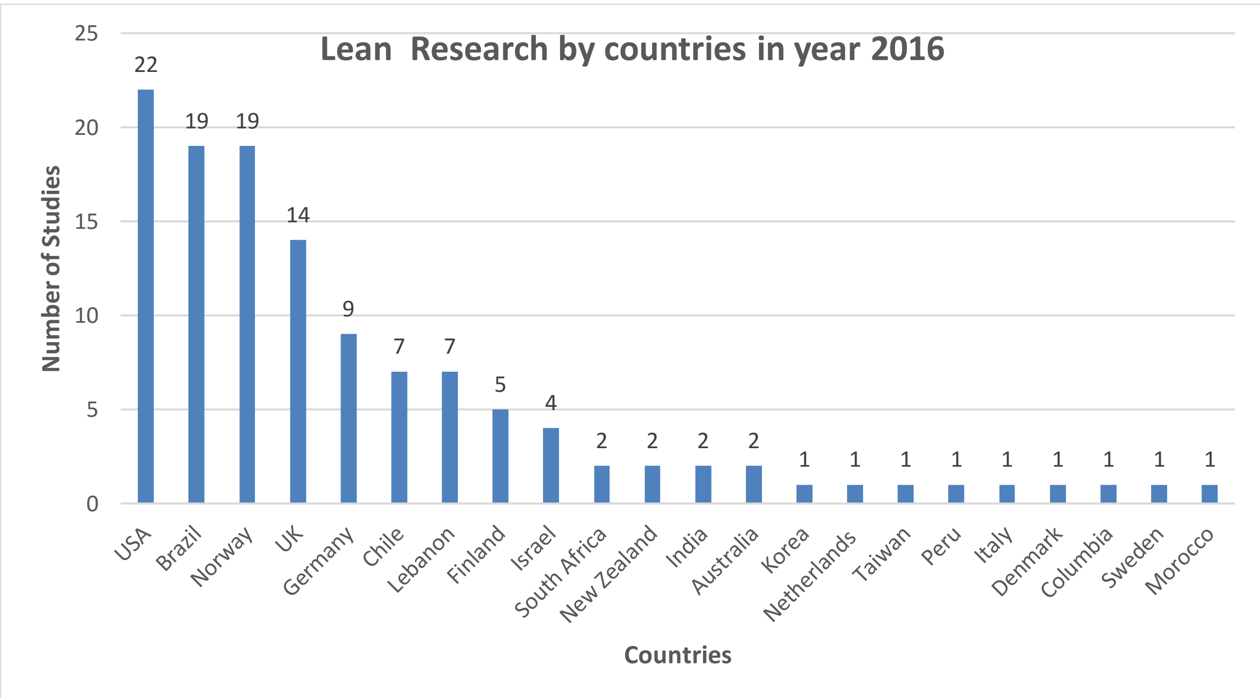

Figure 23: Lean construction research by location

Figure 23 represents the contribution of various countries in lean construction research for year 2016. Every year IGLC conference is organized in different locations, in 2016 it was held in Boston, USA. Most studies were conducted in USA, followed by Brazil and Norway. Some studies have multiple authors from different countries, in this case country of main author was considered.

4.3.4. What are key areas or problem in areas that requires further research?

To answer this question, two separate categories were created during analysis of the studies with title 'Limitation/Barriers' and 'Remarks/Future scope' as mentioned earlier in section 3.1.4. of chapter 3. These category only deals with the limitation and scope mentioned directly in the research study, therefore no personal assessment was involved to represent the results. The results are discussed here based on the focused area or context of the studies.

In area of **sustainable development,** lean-green research is considered as a one way research[79]. All researches emphasis on use of lean to achieve sustainable development. It was recommended to research on the other way, if it is possible to achieve more efficient lean construction by using sustainability principles. It notable that majority research identifies synergies between lean and green from theoretical perspective only, so there is big research gap in quantifying measurable benefit of lean and green79,[80]. Complex requirement for sustainability certification might affect number of green building which can be optimized by utilization of lean principle by reducing waste in certification process as identified by Weinheimer[81] in Germany.

There is possibility to combine lean construction and **value management**, since the both are advantageous individually for value generation.

In terms of **safety** there are barriers like resistance to change, lack of knowledge and long term vision of added cost that can be overcome by considering CBA method and combining it with Last planner system[82]. It is also recommended to implement CBA in tendering stage of the public sector for decision making and avail best alternative from received proposals.

[79] (Wu & Wang, 2016)
[80] (Johnsen & Drevland, 2016)
[81] (Weinheimer, 2016)
[82] (Karakhan, Gambatese, & Rajendran, 2016)

Quality plays an important role in success of construction project and it is connected to all construction stages. Pre-construction and post construction stage affects the quality most. It also defines customer satisfaction. Always there is a fraction of cost goes to quality issues and rework due to that. Quality related studies were only 9% in 2016. Quality should be integrated into process that requires management commitment and training to personnel.

Target value design was investigated for real estate developememt to optimize design phase and it could be utilize for building construction. But there was lack of quantification to use fully TVD in other construction areas. Quantification can be used in future research to understand priorities in work to be completed at early stages[83].

Visual management through Unmanned Aerial Vehicles (UAS) could reduce inspection time over large construction sites and allow immediate response to make decision making process more effective[84]. It is proved that 5S is beneficial to small projects, so there is possibility to implement it on large scale projects for better co-ordination and PPC.

Collaboration between stakeholders was noticed as frequent barrier for implantation of various lean tools in different areas like historic preservation, inspection, safety etc. When there are people from more than one country involved in project, there are problems with information overload, unstructured information and underrated communication. There is need for comparative study to identify relation between project delivery and communication.

There is connection between **customer satisfaction** and number of defects. In some cases overall customer satisfaction was not affected by minor defects and repair of defects within warranty period. So, further research is needed to analysis more data from different company in different countries to understand how customer satisfaction is affected as it is important base for lean construction[85].

After providing **training**, it is also important to know how efficient the training was. So there is need to analysis this efficiency to improve understanding of lean project delivery and prevent internal resistance.

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83 (H. M. M. Neto, Costa, & Thomas, 2016)
84 (Costa, Melo, Álvares, & Bello, 2016)
85 (Milion, Alves, & Paliari, 2016)

In a literature study similarity between lean principles and **project alliancing** was noticed which can serve as a good starting point for the owner who wants to implement lean delivery. Further research could determine whether project alliancing would benefit from workplace standardization or any other lean construction tool[86].

Supply chain management in construction lacks standardization and reliable and accurate data records. There is need for research in pull based planning to automatically update 4D models with progress[87] and forecast demand to avoid lack of material on site[88]. Administrating process should be focused with lean philosophy to evaluate and review the overall process[89]. Successful case studies in particular construction sector should be followed in other sectors or type of construction. The same challenges and future scope applies to production planning and controlling with lean philosophy[90]. Lean tools like high mix low volume faces bureaucratic hurdles and traditional organizational structure. New development like this in lean management derived from theory should be validated through case study[91]. Lean simulations and frameworks should be applied and studied in real construction project to test the results[92,93,94.]

There is also need to research about improving energy efficiency in **existing building,** since new building are not sufficient in numbers comparable to existing building for sustainability purpose. In year 2016, only two studies contributed to application of lean on existing buildings.

The one study was about preservation of historic building in Jeddah city. A process map was developed for each stage to reduce wastes and failures. This kind of project have similarity in implementation with new construction but they have different challenges because of unforeseen conditions, material availability and disrepair[95].

The other was a case study to renovate residential building by improving workflow and productive time. They noted 40% of time spent by workers was value adding and the

86 (Young, Hosseini, & Lædre, 2016)
87 (Aasrum, Lædre, Svalestuen, Lohne, & Plaum, 2016)
88 (Dallasega et al., 2016)
89 (Rossiti, Serra, & Lorenzon, 2016)
90 (Binninger, Dlouhy, Oprach, & Haghsheno, 2016)
91 (Korb & Sacks, 2016)
92 (Ma & Sacks, 2016)
93 (Neeraj et al., 2016)
94 (Poshdar et al., 2016)
95 (Alsaggaf & Parrish, 2016)

rest was waste[96]. Lean was used to achieve continuous workflow and level scheduling. Additional lean tools were applied to multi-skilled teams included transfer of activities between workers, coaching among workers, balancing of work, reallocation of activities, collaboration between workers, just in time delivery, security of materials, autonomous self-controlled teams96. Result was increase in productivity and decrease in overall time. Further research was recommended to search in what circumstances and under what situations working in multi-skilled teams will increase labor productivity.

BIM was used to combine with the Last planner system, Lean project delivery, TFV theory. Potentials of combined implementation of BIM and Lean noticed are;

- Production planning through a 4D scheduling software that virtually construct first and provide chances to improvement in flows.
- Cost monitoring through 5D BIM.
- Safety training through safety simulations for example emergency exist plans, scaffolding requirements.
- Logistics plan visualization for improved productivity in operations like loading, unloading.

Limitations recorded for implementation are related to human aspects mostly. For example lack of training and skills was common in most projects for implementation of lean principles on site. Moreover this training costs money and time, which some companies does not want to spend. That also limits the level of details in BIM and its implementation to achieve lean construction. A study[97] suggest to use BIM station to make implementation more efficient among the workers on site, educate all participate about BIM and how it will benefit the overall construction process to avoid the barriers of human aspects. That will ultimately reduce the amount of non-value adding activities. It should be applied from strategical level to make organizational change happen[98]. Also, support from public authorities (government) could be beneficial for successful BIM-Lean implementation[98].

To reduce waste and non-value added activities from **facility management** process and enable continuous improvement BIM and Lean should be collaborated through life

[96] (Vrijhoef, 2016)
[97] (Vestermo, Murvold, Svalestuen, Lohne, & Lædre, 2016)
[98] (J. d. P. B. Neto, 2016)

cycle time. At present, separate models are generated for the operation and maintenance phase since no CAFM solution can process complete model for planning and construction and FM software cannot read BIM data. Particularly in Germany, interlinking standards for BIM and FM is required and new tools of lean construction should be examined to apply on facility management[99].

Ancillary areas in research to be considered for further work

The studies were classified in mainly three construction stages as discussed in section 3.1.4 earlier. Figure 24 shows the research studies conducted in each construction stages for year 2016. 39% of the total studies contributed for construction stages. Pre-construction stage was researched 8% less in number than studies in construction stage minimum research was found related to post construction stage. Rest 31% studies were not focused in particular construction stage, but discussing problems in general construction industry. So, 35 studies were researching about throughout construction process. From 2 post construction studies, one was discussing inspection challenges after construction through simulation techniques. The other one was case study about improving process of obtaining the Certificate of Occupancy for residential building projects. Clearly, there is huge gap in research for post construction stage. There should be more post construction research to balance overall construction process to make it more productive and result oriented.

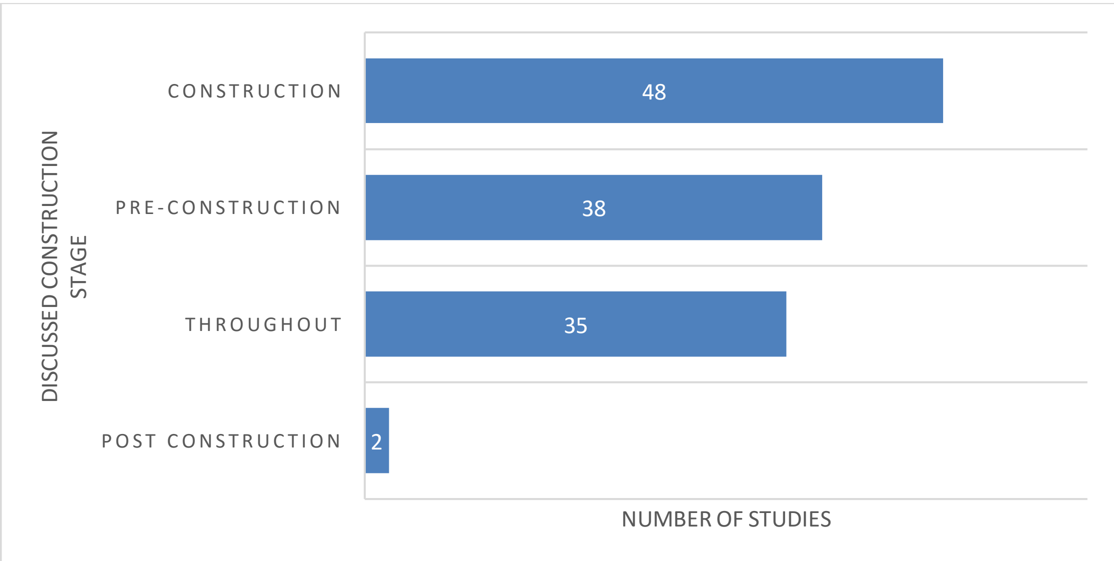

Figure 24: construction stages disscussed in research studies

[99] (Beck, Schmalz, Heyl, & Binder, 2016)

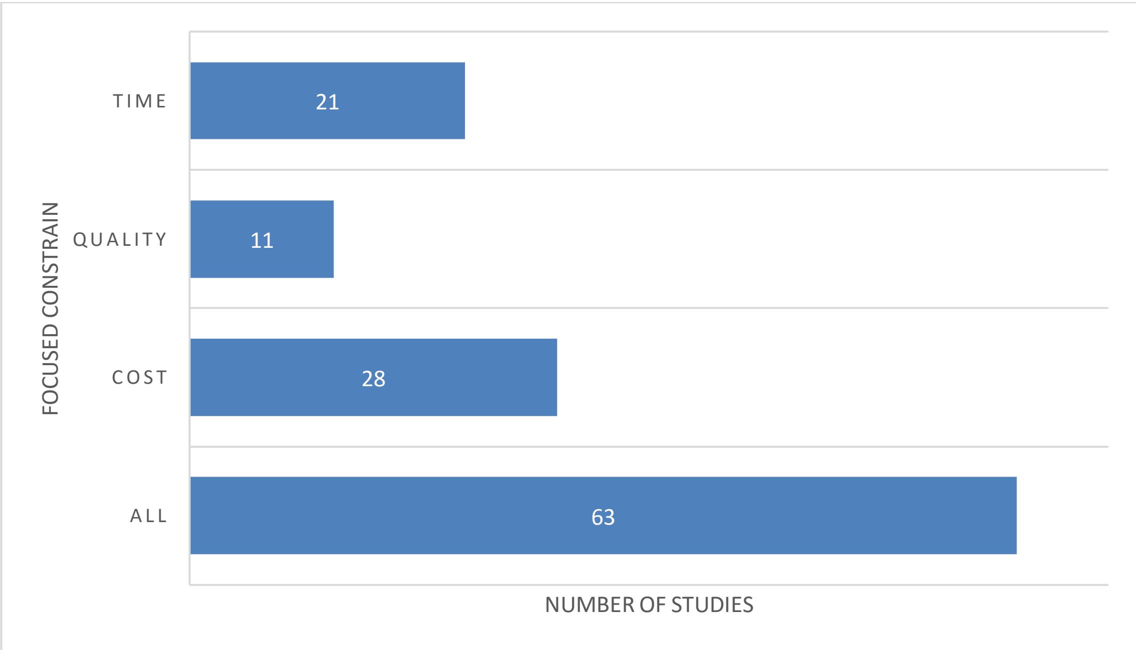

Figure 25: construction management constrain focused in research

Similarly, Figure 25 depicts focussed contrain of construction management as disscussed in section 3.1.4. in research for the year 2016. It can be noticed that around 51% of the studies does not specifically focus on contrain of time, cost or quality. Cost is focused in 23% research pappers, then 17% was studied with time as focus point to reduce overall project duration and time of major activities. Only 9% studies focused on quality, which is less comparatively other research. The quality related research was driven by lean principle like waste reduction, customer satifaction and collaboration. Future focus should also consider quality aspect of construction to avoid reworks and defects.

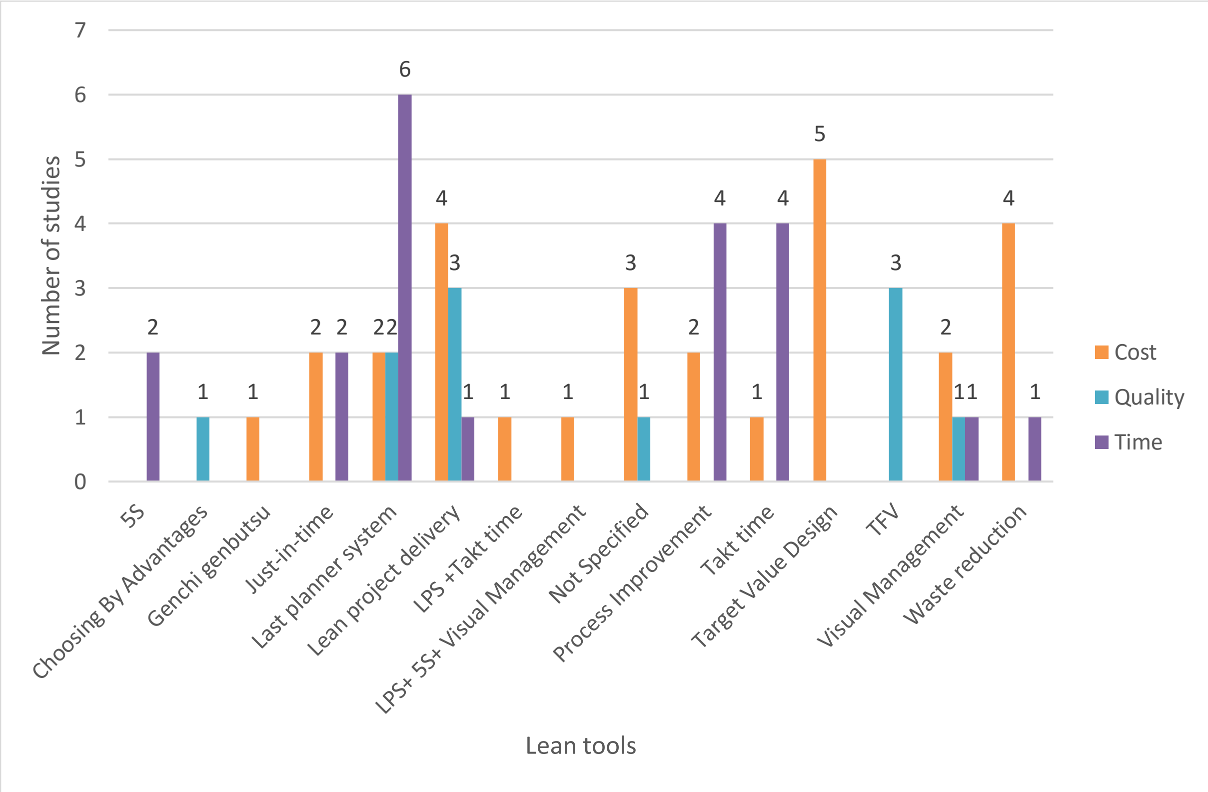

Figure 26: construction management contrain focused by different lean tools

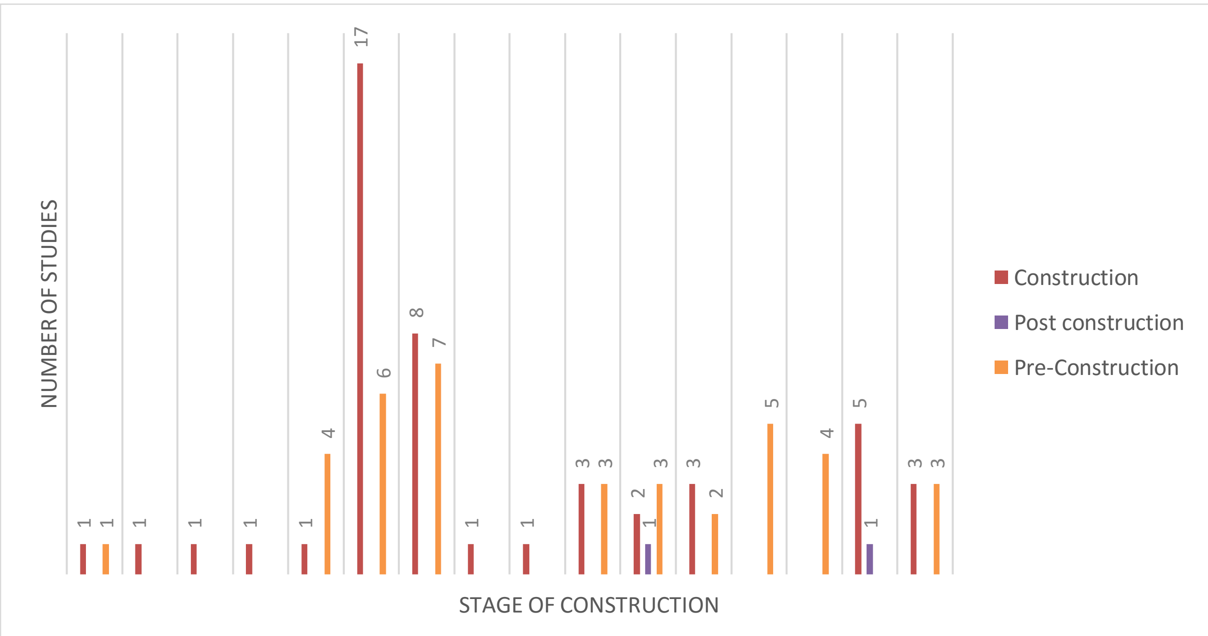

Figure 27: lean tools used in different stages of construction

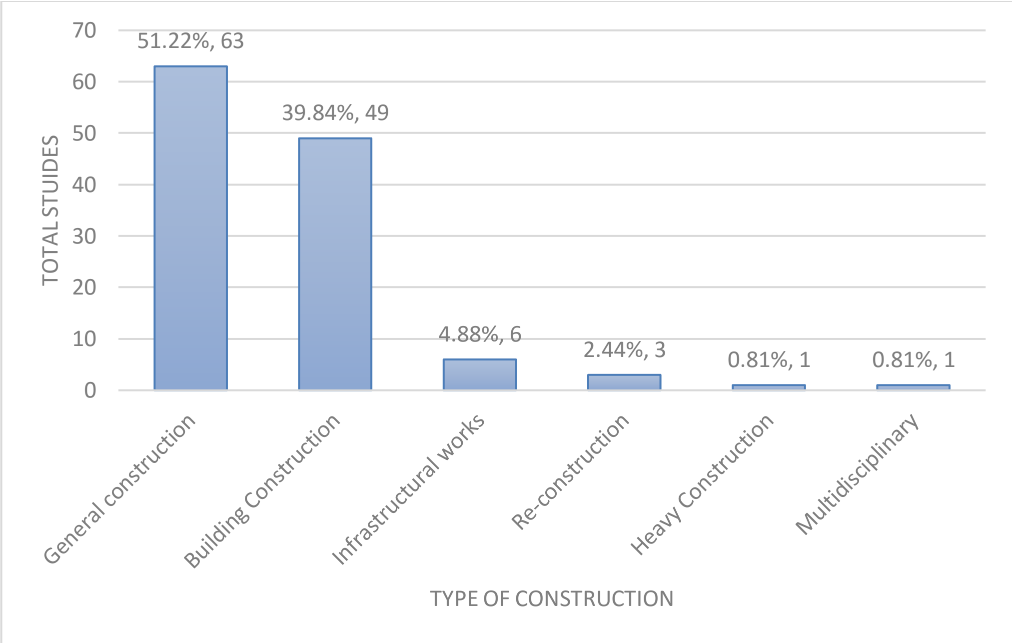

Figure 28: Breakdown of research according to construction type

Figure 28 represents different type of construction and research studies involved with that in year 2016. These main type of construction works are classified according to Eurostat[59] document as mentioned earlier in section 3.1.4. General construction contributes around 51% which does not limits the utilization of results in particular type of construction. The next huge amount of research was focused on building construction that is 40% of total research work. It means 9% comprises other type of construction work like all infrastructural works, heavy construction works, re-construction works and multidisciplinary works. There is little doubt that lean construction research work is not stretched to other type of construction. Infrastructural works and re-construction works are contributing large volume in construction industry, so, these sectors should be developed along with the building and general construction works. 9 % studies proved that lean construction principles can be successfully implemented and improve construction practice in other sectors too. But it needs more theoretical and empirical validation to be accepted by general practitioners.

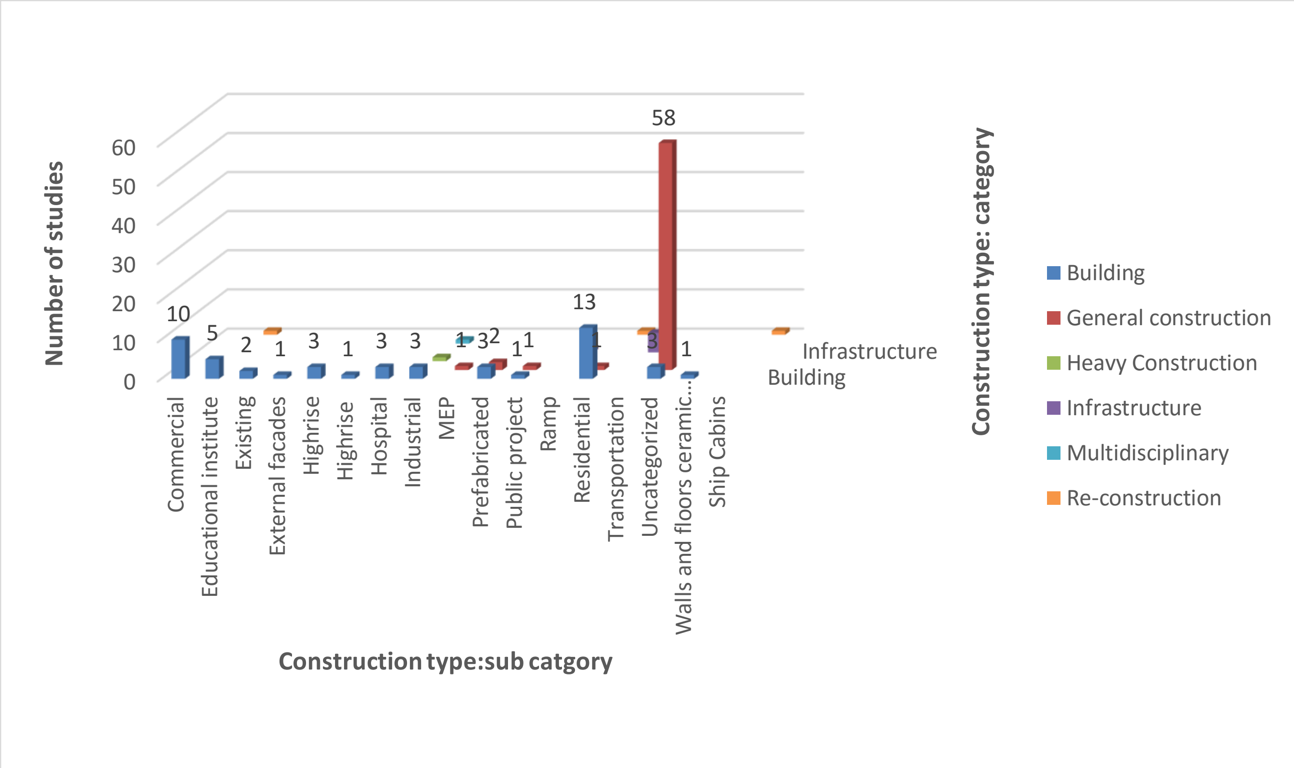

Figure 29: Further breakdown of reseach in construction types into construction sub-categories

Figure 29 gives detailed breakdown of construction type discussed above and groups it into further sub-categories as discussed earlier in section 3.1.4. General construction is about overall construction practice so mostly it remains uncategorized in sub classification. Nevertheless, it also comprises of single study in MEP works and public works two studies in prefabricated works. Re-construction works consists of residential, ship cabin refurbishments and educational building which is existing university building and was failed to meet deadlines. Multidisciplinary case study involved more than one type of construction to derive the conclusions which were hospital, oil industry and shipbuilding. Heavy construction project study was about facility with complex network of conveyer belts of different angles, underground tunnel, geometrically complex buildings where high levels of details and coordination is required. Research in infrastructure was concerned with transportation and mostly highways. It is also require to consider other type of infrastructure like water, harbors, railways etc. for future research.

Lean research in building construction is covered by various type of building like commercial, educational, residential, public buildings etc. Residential and commercial building are being researched most among other types. This classification gives idea about the current status of research and direction to identify needs in other type of building construction for future works.

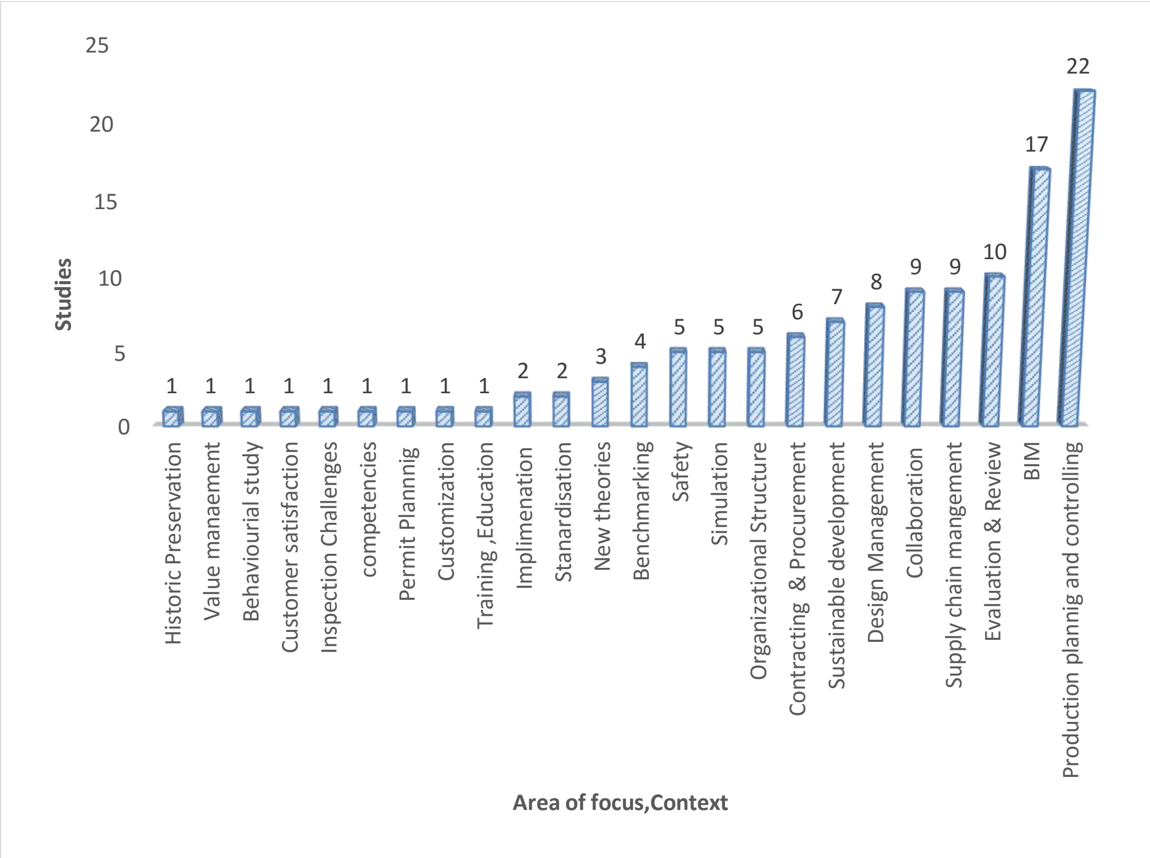

Figure 30: Breakdown of total studies according to context

Figure 30 gives overall study classification according to their context from year 2016. This graph includes also studies with TPS category. It represents overall research trend of lean construction in 2016. Lean principles were frequently implemented in construction production planning & controlling (22) and Building information modelling (17). Research studies count five to ten is of safety, simulation, contracting, design management, evaluation & review. This number can be considered as good enough for given research area. But there are many areas less explored as less than five studies published in a year. The future research focus should be in these areas which are equally responsible for successful completion of project efficiently. Some of these areas are much important like customer satisfaction, competences, training and education, development and implementation of new theory. Overall project success will depend on effective performances of this sectors because this can affect processes and activities throughout the project.

CHAPTER 5: DISCUSSIONS

This chapter discusses the result of analysis to compare them with another study from the past. The purpose is to generalize trends in lean research over time. Readers have an overview of the lean research development in each category mentioned earlier in previous chapter. It will give brief idea to researchers about future research scope in lean construction.

Earlier in year 2011 one similar study was conducted with a main objective of aligning lean construction research with TPS framework[8]. It involved lean research from IGLC conferences between years 1996 to 2009. In 1996, it was first official recorded conference, before that between 1993 and 1996 there were workshops held to share the knowledge of lean construction without conference proceedings. The purpose of this study was to raise awareness of lean research amongst lean researchers in construction, which is also one objective of this study to check further deviation in research over time since 2009. As previous research was part of doctoral thesis, it analyzed 592 research papers from IGLC.

This chapter will discuss how research trends have changed from year 2009 to year 2016 based on a study by Jacobs[8].

TPS research representation

Philosophy research constituted 2% of total studies. TPS research representation in 2009 focused on process was 28.7%. People and partners model was focused by 7.6% researchers. Problem solving model contributed 2.1 %. Total 40.4% of studies were aligned to TPS framework. Rest 59.6% studies were Non-TPS categories including outliers. Comparing it with research representation in 2016, improvement can be noticed in all TPS categories except People & partner. Process oriented research was 30 %, Philosophy was 6.5 %, problem solving was at 6%, and people & partner was at 2% which is less then past research. Non-TPS categories were 50% in 2016, more than earlier, that means lean research is deviating from TPS framework to develop lean construction research. Process research in construction exhibited steady research representation at IGLC conferences between 1996 and 2009 which seems to continue till 2016.

Distribution of studies within TPS category

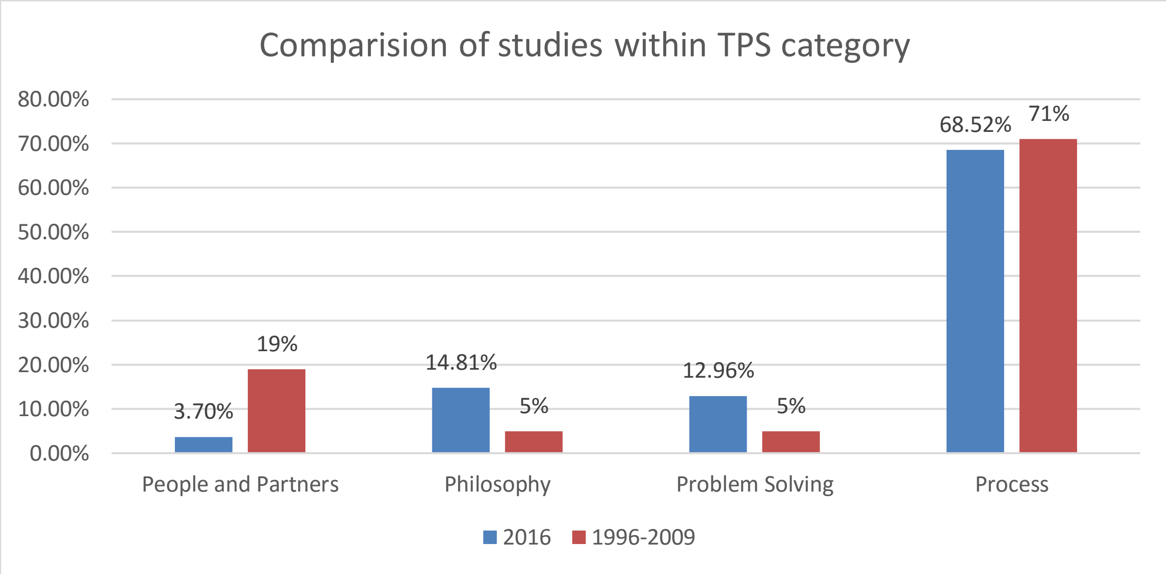

Figure 31: Comparision of TPS studies

Figure 31 informs about TPS study distribution then and now. It only compares percentage against total number of TPS studies. It can be noted that majority of studies were related to the application of Process principles. Process studies maintained same level of interest among researchers. The Last Planner became known as a Process model developed by Ballard and Howell[100]. The Last Planner system was researched mainly as process improvement tool which was contributing 67% of total process research in 2016. Also, Jacobs[8] noted that in previous study that Last planner system was major tool for researching Process between 1996 and 2009. There is improvement in Philosophy and Problem solving research from 5% to 15% and 13% respectively. On the contrary, People and Partners research was declined to 4% from earlier 19%.

Non-TPS research trends (According to context)

Development of new theory for construction has gained huge attention from 1996 to 2009, mainly by noticeable researchers like Ballard, Howell, Koskela who shared importance of applied theory in construction. Theory development was 8.9 % during that time which was decreased afterwards to 1.6% in year 2016.

[100] (Howell & Ballard, 1998)

Benchmarking is a tool designed for measuring the quality of organizations in terms of policies, programs, products and strategies, among others[101]. Benchmarking category studies compared their results with the best process or performances from other industry or projects. This research contributed 2.7% of all studies and in 2016 it was 3.3 % studies. The number of studies were increased by 0.6%.

Research on sustainable development problems signifies 1% of the IGLC research studies between 1996 and 2009. That sector in 2016 was 4.9%, higher than earlier obviously because of the various initiative for sustainable development and green construction during that time. It was noted that sustainable lean research was conducted mostly in Scandinavian countries until 2009, but in 2016, countries like Chile, USA, Australia and Germany also contributed.

Design management discuss about studies which tries to improve efficiency of design stage or in supply chain by reduce waste over there. Design management hosts lean tools like TFV for improvisation[102]. Design management research studies were 8 out of 123.

Organizational change is associated with internal change in management to apply lean strategy which is different than long term thinking of philosophy category. This research was raised in 2016 to 2.4% from 1% in 2009. That suggest that more companies want to change internal structure to accommodate lean thinking.

Lean understanding by simulation was introduced by 1% studies until 2009 that has been increased up to 2.4% in 2016. Similarly, Review and evaluation of existing literature and methods has gained more attention with 2.4% studies earlier from 1%. Whereas design management studies were 8% in 2009, that has been decreased to 6.5%. Design management deals with integration of construction design phase into management to have better results which is different from people and partner category of TPS framework.

Studies which does neither follow TPS framework nor Lean principle, considered as outlier. Number of outlier were reduced in 2016 (6.5%) that that of in 2009 (10%). Prefabricated studies were 1% which increased by 2016 up to 4%. Safety related research

[101] (Mejía-Plata et al., 2016)
[102] (Jorgensen, 2006)

was conducted to prevent accidents and avoid small injuries during construction which contributed 3% of studies back in 2009 and 3.3% in 2016.

Lean research by countries

USA, Brazil and UK were top three countries between 1996 and 2009 for publishing lean construction research. In year 2016, Brazil and USA remains on the top but with Norway as third position, UK was on fourth place in ranking by number of publications. Overall lean research by location suggested that 67 % studies were conducted by researchers from USA, Brazil and Norway, UK and Germany. Countries like Lebanon, India and Morocco are also engaging in lean research which were not present before 2009. So, we can say that lean construction is getting accepted by more & more countries around the world which was main purpose of IGLC to involve more people in research around the world in response to global challenges.

Research Methodologies

Manly four methods were considered in previous research, general qualitative research, case study, action research, and interviews. General category is defined as „Qualitative research provides detailed descriptions and explanations of a phenomenon studied rather than providing and analyzing statistics" by Jacobs[8]. In this study general qualitative research was divided into further specific methodology to have clear understanding of the applied methods. The definition of three other methods are same in both study so they can be compared to have an idea about trends in methodologies used.

General qualitative research was 71% as it was generalized for all qualitative methods, case studies were 27%, action research and interview were both 1% of the total TPS studies. In this study, case studies were 43% of total studies, action research was 3% and interview was at 8%. Clearly, there is increase in use of all three methods to imply results. Also, they are developing creative ways to research based on new methodology from other sectors like simulations, computation case studies as noticed in this study. Some of these methods are mentioned in literature review chapter in section 2.7.

Barriers and Limitations

Almost all studies faced problem of cultural change at some point in project. The studies with clear barriers to implement lean states the lack of knowledge, insufficient training, poor collaboration & communication and resistance to change as main limitations to be taken into account while implementation of lean.

Clearly, there is a need to change this behavior among project stakeholders to successfully implement lean and collect rewards. That is only possible via cultural change in organization. To avail this changes following measures are required to be taken,

- Reshaping the thinking and behavior of employees through continuous training and immediate feedback from supervisors.
- Performance based rewards, flexibility in work hours and adaption to other local condition.
- Obligatory training for all principle managers with a test to prove the knowledge and afterwards application of learned outcomes.
- Development of policy and inform everybody about it to transmit the objectives.
- Overall group performance should be monitored frequently to understand and inform the problems to appropriate management level for solution.
- Leader should adapt the change first, then it can be transferred to the employees.
- Creating a leaning environment.
- A person needs a secure work environment and team feeling.
- Motivation through targets and performance measurement.
- Development of a sharing culture to share knowledge and experience.

After applying this measure its effectiveness should be verified. That can be done by measuring percentage of profit, number of solution generated over certain periods, average man hour consumed and customer satisfaction level.

Developing core capabilities and benefits from lean construction requires these cultural and organization changes. There is need of more studies related to people and partner’s category to understand issues related and find solutions.

CHAPTER 6: CONCLUSION

This chapter provides summary of the thesis as well as evaluations of the study with respect to formulated questions. It also draws conclusions from the result & discussions of analysis. Lastly, main recommendations for future works are presented.

Lean construction is adaption of Toyota production principles and its implementation in construction process considering construction is a special kind of production. Construction results in a unique product whereas manufacturing results in mass production. Since construction characteristics are complex in nature, it can be said, that significant amount of work has been done in adaption of lean research for construction. To understand state of art and trends in particular sector of lean construction, one needs to dig deep for relevant material from all available sources. It felt necessary by self-experience to organize and categorize researches in order to identify needs for future. This thesis tried to analysis latest research publications in lean construction to structurally organize and reveal trends in it. Furthermore the studies were examined them for their compliance to the Toyota Production System (TPS). Analysis was conducted on conference proceedings of International Group of Lean Construction (IGLC) from year 2016, considering IGLC as most updated resource of lean construction research among others.

With respect to objectives and research questions of the thesis, following conclusions can be drawn from the study,

In order to understand lean construction trends and its relation to TPS, it is essential to know its roots in lean production and reasons of originating of reducing waste. Considering these wastes in the construction and its supply chain, it is concluded that still there is large room for innovative theory and empirical studies in lean construction. These research gap could be fulfilled by intercommunication between professionals from industry and researchers from institutes.

The studies with clear mentioned barriers states that the lack of knowledge, insufficient training, poor collaboration & communication and resistance to change are main limitations to implement lean construction tools. These could be overcome by integrating measures described in chapter five.

Six step research was carried out to conduct Content Analysis on IGLC studies. Content analysis is best suitable method for this of type study to draw interfaces and define trends on large database like IGLC by considering various aspects of documentation. It gives opportunity to construct categories for analysis based on requirements as well as testing for reliability and validity. The objective of this thesis to structurally organize documentation of lean construction research is fulfilled with this research method and resulted in the form of charts with different aspects of construction.

Total 123 conference proceedings were studied for content analysis from IGLC 2016. After reviewing each study, it was assigned to different categories depending on various factors. The categories included location of the study, construction stage and constrain focused, type of construction analyzed, TPS principle followed, context of the study, lean tools utilized to implement lean theory, Research methodology, advantages noticed, barriers for implementation and future recommendations.

To fulfill second objective of this thesis, lean tools need to understand which roots back to TPS framework and its 14 principles. Based on these 14 principles and lean tools, each study was assigned to either a TPS category or Non-TPS category. Those studies which does not accompany TPS or any lean tool are considered outliers.

This categorization summarized into a single table and from this table various charts produced representing trends in lean construction with the help of Microsoft Excel software. The charts generated are based on author's knowledge of problems in construction industry. It illustrations that what kind of results could be achieved by this analysis. Many more charts with different facets based on these categories could be generated by manipulating them according to requirements.

These charts gave the answers to the research questions raised earlier which are summarized below.

1. Which Principle of TPS have been mostly considered under researches?

- Overall 54% studies were complying with TPS framework. Out of these 54%, 'Process' related principles were widely (69%) considered and 'Peoples and Partners' related principles were least (4%) followed by researchers.
- The other two 'Problem solving' (6%) & 'Philosophy' (7%) are considerable in amount but not good enough. The Last Planner System (22%) was most common lean tool utilized by researches to follow 'Process' principles followed by Lean Project delivery (21%), waste reduction (9%) and Takt time planning (7%).
- Building Information Modelling was maximum pursued subject to combine with lean. Tools like 5S (2%) and Genchi Genbutsu (1%) which relates to 'problem solving' category are not as much utilized as above mentioned tools for research.

2. What research methods were mainly used?

- Case study research (43%) was largely considered to implement lean tools and literature review (24%) was second largest in number.
- Furthermore in case studies 'Production planning & controlling (23%)' and 'BIM (15%)' was main focus, while in literature review 'Evaluation & Review (20%)' category was focused.
- Out of 53 case studies '66% studies represented Building Construction and from 30 literature review mainly conducted for 'General Construction (83%)'. Within Building Construction, Residential (20%), and Commercial buildings (16%) are being researched more among other types. That means there is imbalance between new theory development and application of developed theory.
- Lean construction research should be balanced both ways for better results and improvements and extended to other types of construction works. New methods, which were less considered also need to be focused like Action Research (2%), Design Science Research (5%) and Simulation (3%).

3. What is the contribution of different countries in research in last year?

- Analysis of lean construction research by location suggested that 67 % studies were conducted by researchers from USA, Brazil and Norway, UK and Germany.

Following summaries are noticeable through comparison of these results with previous research considering time aspect,

- The analysis shows that lean construction research has gained interest and gave rise in number of conference papers in IGLC comparing it to previous study. Overall trend in TPS representation is similar as it was in 2009 (Process, 71%), which was also more aligned towards 'Process'. The noticeable change is in people and Partner oriented research, which should be increasing to avail change in cultural and behavioral aspect, instead of declining by 15%.
- 'Organizational change' research was increased in 2016 to 2.4% from 1% in 2009. That suggests that more companies want to change internal structure to accommodate lean thinking.

- Other than above mentioned five countries like Lebanon, India and Morocco are also engaging in lean research which were not present in IGLC research database before 2009 that determines the growing acceptance and interest of lean construction round the world.

4. What are the key areas or problem in areas that requires further research?

Based on studied literature, there are still gaps in these broad research areas that demands further investigations;

- Generalizing in construction to defend unique nature of construction projects.
- Customizing TPS theory for construction industry and new management system for lean construction.
- Lean based Improvement of energy efficiency of existing building.
- Evaluation study after implementation of lean to analyze efficiency of implementation.

Besides, future lean construction research works should embrace following areas;

- Collaboration of Lean and FM to reduce waste and non-value added activities from facility management process and enable continuous improvement throughout life cycle.
- Infrastructural works and re-construction works were only 7% experimented with lean thinking in 2016. These 7 % studies proved that lean construction principles can be successfully implemented and improve construction practice in other sectors too. But it needs more theoretical and empirical validation to be accepted by general practitioners.
- Strategic implementation of BIM and lean to overcome barriers related to human aspects. Possibility of support from public authorities should also be investigated. For example, mandatory BIM- lean submission for public projects.
- As criticized by Womack[103], Job securities play important role in success of lean theory, but no studies in construction considered this factor for further research.
- Labor productivity, how & under which conditions lean can increase labor productivity?

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[103] (Womack, Jones, & Roos, 1990)

As intended, this thesis indicates trends in lean construction research and aware researchers for balanced research. This study suggests that, some of the points in lean construction are more researched than others. For example, research studies related to strictly Quality constrain, Post-construction stages, training issues are least in number that needs attention.

Considering significance of TPS framework in lean construction, research should comply with TPS as much as possible. Lean constriction research was aligned towards one category of ‘process’ sidestepping others. Future works should be balanced between all four categories to gain same value as in manufacturing and successful implementation of lean thinking in construction. Importantly, barriers related to human aspects & resistance to change must overcome by integrating more efforts in ‘People & partners’ and ‘problem solving’ related research for construction industry.

Declaration of Authorship

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

Date	Signature of the student

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APPENDICES

Appendix A: List of 123 IGLC papers studied for the thesis.

Aasrum, J., Lædre, O., Svalestuen, F., Lohne, J., & Plaum, S. (2016, 2016/07/20). *Communication in Building Design Management: A Comparative Study of Norway and Germany.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Abou-Ibrahim, H., & Hamzeh, F. (2016, 2016/07/20). *BIM: A TFV Perspective to Manage Design Using the LOD Concept.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Al Hattab, M., & Hamzeh, F. (2016, 2016/07/20). *Modeling Design Workflow: Integrating Process and Organization.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Alsaggaf, A., & Parrish, K. (2016, 2016/07/20). *A Proposed Lean Project Delivery Process for Preservation Projects in Jeddah City, Saudi Arabia.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

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Alves, T. d. C. L., Needy, K. L., Walsh, K. D., & Chan, D. (2016, 2016/07/20). *Understanding Inspection Challenges in the EPC Industry: A Simulation Approach.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Andersen, L. (2016, 2016/07/20). *Design and Engineering – Material Order.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Antunes, R., González, V., & Walsh, K. (2016, 2016/07/20). *Quicker Reaction, Lower Variability: The Effect of Transient Time in Flow Variability of Project-Driven Production.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Arroyo, P., & Gonzalez, V. (2016, 2016/07/20). *Rethinking Waste Definition to Account for Environmental and Social Impacts.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Arroyo, P., & Valladares, O. (2016, 2016/07/20). *Last Planner System: Implementation, Evaluation and Comparison of Results in the Construction of a Social Housing Project in Chile.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Aslesen, S., & Tommelein, I. D. (2016, 2016/07/20). *What "Makes" the Last Planner? A Typology of Behavioral Patterns of Last Planners.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Awada, M. A., Lakkis, B. S., Doughan, A. R., & Hamzeh, F. R. (2016, 2016/07/20). *Influence of Lean Concepts on Safety in the Lebanese Construction Industry.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Ballard, G., Egebjerg, C., Bølviken, T., Endresen, S., & Ballard, B. (2016, 2016/07/20). *Filmmaking and Construction: Two Project Production Systems.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Beck, S., Schmalz, S., Heyl, J. v., & Binder, F. (2016, 2016/07/20). *Optimizing the Value Stream – Application of Bim in Fm. Status Quo in Germany.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Bekdik, B., Hall, D., & Aslesen, S. (2016, 2016/07/20). *Off-Site Prefabrication: What Does It Require From the Trade Contractor?* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Bhaidani, N., Rybkowski, Z., Smith, J. P., Choudhury, I., & Hill, R. (2016, 2016/07/20). *Percent Planned Complete: Development and Testing of a Simulation to Increase Reliability in Scheduling.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

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Dallasega, P., Marcher, C., Marengo, E., Rauch, E., Matt, D. T., & Nutt, W. (2016, 2016/07/20). *A Decentralized and Pull-Based Control Loop for On-Demand Delivery in Eto Construction Supply Chains.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Damaj, O., Fakhreddine, M., Lahoud, M., & Hamzeh, F. (2016, 2016/07/20). *Implementing Ergonomics in Construction to Improve Work Performance.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Daniel, E. I., Pasquire, C., & Dickens, G. (2016, 2016/07/20). *Exploring the Factors That Influence the Implementation of the Last Planner® System on Joint Venture Infrastructure Projects: A Case Study Approach.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Dave, B., Seppänen, O., & Modrich, R.-U. (2016, 2016/07/20). *Modeling Information Flows Between Last Planner and Location Based Management System.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Demir, S. T., & Theis, P. (2016, 2016/07/20). *Agile Design Management – the Application of Scrum in the Design Phase of Construction Projects.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

Dlouhy, J., Binninger, M., Oprach, S., & Haghsheno, S. (2016, 2016/07/20). *Three-Level Method of Takt Planning and Takt Control – a New Approach for Designing Production Systems in Construction.* Paper presented at the 24th Annual Conference of the International Group for Lean Construction, Boston, USA.

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Appendix B: Intra-rater reliability test

INTRA-RATER RELIABILITY TEST, Coefficient 0.92				
Author	**Title**	**Context/Subject matter**	**TPS Principle**	**Remarks**
Wu, Peng; Wang, Xiangyu	A Critical Review of the Factors Affecting the Success of Using Lean to Achieve Green Benefits	Sustainable development	Other	Same as earlier
Khan, Sheriz; Tzortzopoulos, Patricia	A Framework for Evaluating an Action Research Study on Lean Design Management	Design Management	Other	Same as earlier
Abou-Ibrahim, Hisham; Hamzeh, Farook	BIM: A TFV Perspective to Manage Design Using the LOD Concept	BIM	Other	Same as earlier
Harris, Britani N.; Alves, Thais da C. L.	Building Information Modeling: A Report From the Field	BIM	Other	Same as earlier
Shou, Wenchi; Wang, Jun; Wang, Xiangyu; Chong, Heap-Yih	Examining the Critical Success Factors in the Adoption of Value Stream Mapping	Evaluation & Review	Problem Solving	Same as earlier
Emuze, Fidelis; Joseph, Kirsten; Pretorius, Erich	Exploring 'Lean' Opportunities for Improving Supply Chain Transaction Governance in South African Construction Projects	Supply chain mangement	Process	Same as earlier
Peñaloza, Guillermina A.; Viana, Daniela Dietz; Bataglin, Fernanda Saidelles; Formoso, Carlos Torres; Bulhões, Iamara Rossi	Guidelines for Integrated Production Control in Engineer-to-Order Prefabricated Concrete Building Systems: Preliminary Results	Production plannig and controlling	Process	Same as earlier
Olivieri, Hylton; Seppänen, Olli; Granja, Ariovaldo D.	Integrating Lbms, Lps and Cpm: A Practical Process	Production plannig and controlling	Philosophy	Mistaken with collaboration
Tillmann, Patricia; Sargent, Zach	Last Planner & Bim Integration: Lessons From a Continuous Improvement Effort	BIM	Other	Same as earlier
Johnsen, Cathrine Andrea; Drevland, Frode	Lean and Sustainability: Three Pillar Thinking in the Production Process	Sustainable development	Other	Same as earlier
Weinheimer, Nina	The Process of Green Building Certification: An Examination Regarding Lean Principles	Sustainable development	Other	Same as earlier
Senior, Bolivar; Nafe, Bennett	Transformation-Flow-Value Views of a Colorado School District'S Prototyping Strategies	Evaluation & Review	Process	Same as earlier

Appendix C: Inter-rater reliability test

Interrater: Mohamed Gamil, M.Sc (ConReM 2017) Classmate

INTER-RATER RELIABILITY TEST, Coefficient 0.83				
Author	**Title**	**Context/Subject matter**	**TPS Principle**	**Remarks**
Alsaggaf, Ahmed; Parrish, Kristen	A Proposed Lean Project Delivery Process for Preservation Projects in Jeddah City, Saudi Arabia	Other	Historic Preservation	Same as earlier
Kim, Taehoon; Kim, Yong-Woo	Activity-Based Costing for Process Improvements	Other	Simulation	Mistaken with TPS category 'Process'
Neto, José de Paula Barros	Approach for Bim Implementation: A Vision for the Building Industry	Other	BIM	Same as earlier
Murvold, Vegar; Vestermo, Aleksander; Svalestuen, Fredrik; Lohne, Jardar; Lædre, Ola	Experiences From the Use of BIM-Stations	Other	BIM	Same as earlier
Awada, Mohamad A.; Lakkis, Bachir S.; Doughan, Ali R.; Hamzeh, Farook R.	Influence of Lean Concepts on Safety in the Lebanese Construction Industry	Other	Safety	Same as earlier
Weinheimer, Nina	The Process of Green Building Certification: An Examination Regarding Lean Principles	Other	Sustainable development	Same as earlier
Covarrubias, Andrés; Mourgues, Claudio; Arroyo, Paz	VSM for Improving the Certificate of Occupancy Process in Real Estate Projects – a Chilean Case Study	Other	Permit Plannnig	Same as earlier
Aslesen, Sigmund; Tommelein, Iris D.	What “Makes” the Last Planner? A Typology of Behavioral Patterns of Last Planners	Other	Behaviourial study	Same as earlier
Harris, Britani N.; Alves, Thais da C. L.	Building Information Modeling: A Report From the Field	Other	BIM	Same as earlier
Sarhan, Saad; Pasquire, Christine; Manu, Emmanuel; King, Andrew	Are Tier 1 Contractors Making Their Money Out of Wasteful Procurement Arrangements?	Other	Contracting & Procurement	Same as earlier
Fosse, Roar; Ballard, Glenn	Lean Design Management in Practice With the Last Planner System	Other	Design Management	Same as earlier
Schöttle, Annett; Arroyo, Paz	The Impact of the Decision-Making Method in the Tendering Procedure to Select the Project Team	Other	Contracting & Procurement	Mistaken with Design Management