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# Optimizing Construction Design Process Using The Lean Based Approach

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## Abstract

**Question:** How lean construction can optimize the design phase to reduce the number of design changes during the construction phase? What are the prevalent causes of design changes that negatively affect the construction and how these changes can be mitigated using lean construction tools and techniques?

**Purpose:** Design changes are considered to be one of the main causes of delay and cost overrun in the construction industry. Many design improvement methodologies have been developed with varying degrees of successes but still, the problem persists in the industry. To address the issue, this study explores the interpretation and application of lean design practices inherited from the principles of lean construction.

**Research Methodology:** A systematic literature review is carried out in two phases: (1) to identify the causes of design changes, (2) to identify lean tools that can mitigate the detrimental effect of the design changes. Lean design practices are identified and further classified into four improvement zones as a flow of information, customer value, collaboration, integration of design with construction, and continuous improvement. The efficacy of identified lean design practices is judged by mapping them against prevalent causes of design changes in the construction. Resultantly, each lean design practice can be assessed based on its capabilities to reduce the design changes that emerged from the actions of owners, consultants, and contractor

**Findings:** This study identified twenty-three (23) lean design practices which can be used as an effective tool to mitigate 38 actions leading to the design changes. It exposes the strengths of each identified tool in effectively managing the design phase.

**Limitation:** This literature review study only includes peer-reviewed papers published by the IGLC, American Society of Civil Engineers (ASCE), and Science Direct and

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excludes the wider construction literature.
**Implications:** The practical implication of this study is that it provides a useful body of knowledge for project teams to manage changes proactively and efficiently by using lean design practices. Moreover, theoretically, it explains the lean design practices and causes of design changes and provides a way forward to the researchers in exploring the efficacy of lean tools in optimizing the design phase.
**Keywords:** Lean Design, Flow of information, Customer's Value, Causes of Design Changes
**Paper type:** Full Paper

# Introduction

Design changes are inevitable in the construction industry. No matter, how well projects are being managed, design changes during the construction phase are causing a detrimental effect on construction outcomes (Chang, 2002). The construction industry is in the continuous struggle for finding out the most appropriate method for reducing the design changes. Different methods like design management as project management, concurrent engineering, design process models, design as value management, design-build procurement, and extensive information technology support are in use for improving design management (Ballard and Koskela, 1998; Karlsson, Lakka, Sulanivi, Hanna and Thompson, 2008; Tzortzopoulos, Sexton and Cooper, 2005; Hiley and Gopsill, 2000). Although these state of the art methods have many thought-provoking and effective new features but still considered to be fragmented and lacked a solid conceptual foundation (Ballard and Koskela, 1998). Up till now, each approach was applied in isolation for improving results without construing the prevalent causes of design changes in actual construction.

With the development of lean construction since the 1990s, and after its successful implementation in the projects, its effectiveness in the design phase was explored by many researchers with positive results in terms of reducing design changes at later stages. The theory of applying the lean philosophy in managing the design processes considers the three different views of design processes as the conversion of inputs to outputs, the flow of accurate and timely information, and value generation. Several studies have been conducted which advocates the efficacy of lean design in reducing the design changes. The application of lean design management on some building projects has also brought good results (Franco and Picchi, 2016). With the recent development of Building information modeling and the internet of things, the lean design approach is moving towards collaboration, partnering, automation, and better visualization of the design product.

However, the concept of lean design is still to gain popularity and acceptance within the construction industry and is required to be extensively researched in captivating the confidence of the construction industry. At the moment, most of the research in lean design is focused on discussing the individual practices like Last Planner System® (LPS®), target value and set-based design, and use of building information modeling in the design process (Freire and Alarcón, 2002; Franco and Picchi, 2016; Tauriainen, Marttinen, Dave and Koskela, 2016; Cousins, 2011). This individuality approach in lean design practices has limited the prospect of the addition of new practices that can be effective during the lean design implementation phase. Few researchers have tried to introduce lean design practices but failed to discuss the efficacy of these practices concerning actions causing the design changes in actual construction (Ballard and Zabelle, 2000; Gambetese and Pestana, 2014; Marzouk, Bakry and El-Said, 2011). The lean design practices must be explored based on its effect in mitigating the causes leading to the design changes.

An effort has been made in this study in identifying the best lean design practices that can be effective during the design phase. The best practices are explored based on the guiding principles of lean design as described in the literature. The literature review revealed that many researchers have tried to explore the efficacy of lean design practices during the design phase however a more rationalized approach is adopted in this study and all the identified best lean design practices are discussed based on their impact in reducing events triggering the design changes. The study is considered to be novel in its approach as it tackles the issues of design changes by carefully combatting the causes of design changes with the most appropriate lean tools and techniques. Very little research has been carried out to explore the efficacy of lean tools and techniques using this approach. The outcome of this study will make the construction industry and new lean practitioners more prudent in making the design phase efficient.

# Literature Review and Background

## Impact of Design Changes on Construction

The importance of the design stage in construction projects can never be underestimated. The client and customer's requirements are physically conceptualized in this stage in the form of drawings and technical specifications. Contractors are pushed for conformance to the requirements as specified in the architectural and engineering design. Any discrepancies in the design may result in design errors and omissions, and excessive rework which at later stages would be very damaging for the construction projects (Chang, 2002).

In this era of modernization, the survival of the construction industry depends on the elimination of wasteful activities within its processes. A poorly formulated design would result in several wasteful practices like errors, omissions, rework, waiting for revised drawings, excessive or shortening of a certain material, etc (Dosumu and Aigbavboa, 2017). These wasteful activities are hindering the cost, schedule, and productivity of a construction project. No matter what is the type, nature, scope, and location of the project, every construction project has to face the dilemma of design changes with varying impacts. Even, well-managed projects have to face the damaging effect of design changes (Chang, 2002).

Many studies have been undertaken to visualize the effect of design changes during construction. Researchers have identified the cost overrun ranging between 5 and 40% in construction projects due to the effect of design changes (Aslam et al., 2019; Yap and Skitmore, 2018; Moura, Teixeira, and Pires, 2007). The impact of design changes on the schedule overrun is also measured extensively in the literature. It's not only about the cost and schedule overrun but reworks due to design changes also hurts the morale of workers and thereby leading to lower productivity (Ibbs, 2005). The indirect effect of the design changes in the form of claims, disputes, loss of reputation, and confidence has further aggravated the detrimental effects of design changes (Zaneldin, 2006).

## Causes of the design changes

In most of the design-related changes, the architects, engineers, and clients seemingly shouldering the bulk of the blame game (Mpofu et al., 2017) because of incomplete conceptualization of the end product and insufficient investigation, thereby enforcing changes later on (Muhwezi et al. 2014). The early design stage involving planning and control can be considered as difficult to evaluate and control against the empirical project milestone because of the lack of physical deliverables and feedback from the construction (Freire and Alarcón, 2002). The complexity of the issue further increases during the construction phase where the contractor finds it difficult in comprehending the design and requirement of the clients, because of their late involvement. Many times compatibility issues between design and construction results into frequent design changes.

Most of the design changes in the traditional design management approach are due to the lack of communication between all the parties within the contract (Aslam et al., 2019). Contractors are seldom involved in planning and design stages, architects and engineers have only formal relations and work in isolation whereas contractors and designers have a contractual relation only. This results in blame games in case of discrepancies. Moreover, if the owner is not fully involved in presenting his exact requirement at the initial stages, there might be the possibility of many scope changes later on during construction. With little collaboration between key players, it would be very difficult to say that all parties are striving to accomplish the mutual goal. Under this environment, all key stakeholders endeavor to achieve their own set goals (Aslam et al. 2019). Contractors foresee their goal as completing the contractual deeds by making the maximum profit. Designers have the goal of pushing the drawings/specifications to the contractor and ensuring its compliance by the contractors. In this arrangement, where everyone is striving for their own goals, problems like design changes are inevitable.

## Struggle towards crossing the barrier

The construction industry has been experimenting with different methods to improve design management so that minimum changes can be made at later stages. These methods include Design management as project management, concurrent engineering, design process models, design as value management, design-build procurement, and extensive information technology support (Ballard and Koskela, 1998; Karlsson et al., 2008; Tzortzopoulos et al., 2005; Hiley and Gopsill, 2000). Although these state of art methods have many thought-provoking and effective new features but still considered to be fragmented and lacked a solid conceptual foundation (Ballard and Koskela, 1998). Up till now, each approach was applied in isolation for improving the results without construing the prevalent causes of design changes in actual construction.

Ballard and Koskela (1998) have very elaborately discussed the anomalies in each of the design management methods. The project management techniques for the design alone proved to be incapable of solving the complex design management because of its inherent assumptions that the work can be broken down into parts and managed independently. Normally work breakdown structure, critical path method, organizational and responsibility chart are the major methods employed in the conversion process. This is considered to be the core perspective in traditional design management because it identifies the exact nature of work to be done as per the stated project requirements generally identified by the Client. However, the biggest drawback in applying this perspective to design is its fragmentation nature in which interaction between different activities is not taken into account which leads to many persisting problems in design management. As per Freire and Alarcon (2002), in a typical project management approach, more influence is given in developing long chains of activities instead of identifying the value or reducing the variabilities within the activities and if used in isolation will lead to rework that could not be visualized.

Similarly, concurrent engineering can only be effective in managing the design changes if collaboration and commitment by all parties exist (Kamara, 2003). The value management approach can be successful if the value is correctly and mutually identified by the architects, engineers, and clients. Like concurrent engineering, the design-build approach has only contributed marginally in improving the design discrepancies because of the lack of organizational integration, unclear clients requirement, and undefined scope of work (Lam et al., 2003). The increased use of informational technology has certainly brought many benefits but still could not optimize design management because of the lack of communication and collaboration between the stakeholders. Even with the successful implementation of Building Information modeling, the design discrepancies still exist in construction. The bottleneck in construction design is not due to deficiencies in information technology or its specific applications, but in short understanding of engineering and construction.

One of the core reasons for these discrepancies is that the design process is conceptualized as a series of different tasks without considering the internal relations between them. An alternate approach was introduced by Ballard and Koskela in 1998 in which design was viewed in three different views: design as the conversion of inputs into outputs, design as a process of flow of information/processes, and design as a process of a value generation. Later on, many researchers have admitted the efficacy of managing the design with these three views (Tzortzopoulos and Formoso, 1999; Deshpande et al., 2011; Marzouk et al., 2011). This perspective of managing the design was named as lean design and derived from lean philosophy.

## Lean Design

Initially, the concept of lean construction was introduced for improving the workflow, meeting the customer's requirements most efficiently, and removing the waste from the construction process/materials. The inspiration for applying lean construction came from lean production, however, with the growing interest and users of lean construction, the definition of lean construction assumed various transformations and extensions (Mossman 2018). According to the Mossman, with the widespread implementation of lean construction around the world, varieties of definitions of lean construction exists to include practices emerging from within the communities. A few of the authenticated definitions of lean construction frequently cited by the researchers are summarized in Table 1.

From these definitions it can be seen that researchers have tried to highlight five important aspects within lean construction definition: (1) it's a new form of production management, (2 ) aims, and objective of lean construction are waste reduction, maximizing value, meeting customers' requirements, and workflow reliability, (3) It is a synergy of different philosophies, techniques/methods (4) It takes into account the Respect for people, and (5) it seeks to pursue perfection through continuous improvement. Most of the researchers have tried to include these five terms in their definitions independently. These five aspects were also mentioned frequently in a detailed analysis carried out by Mossman (2018) in providing the guidelines for developing the lean construction definition.

Table 1: Lean Construction Definitions

| **Authors** | **Lean Construction Definition** |
|---|---|
| *Howell (1999)* | *"Lean construction results from the application of a new form of production management to construction. Essential features of lean construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design to delivery"* |
| *Abdelhamid (2013)* | *"A holistic facility design & delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic & continuous improvements in contractual arrangements, product design, construction process design & methods selection, the supply chain and the workflow reliability of site operations."* |
| *Mossman (2018)* | *"Lean is a practical collection of theories, principles, axioms, techniques, and ways of thinking that together and severally can help individuals and teams improve the processes and systems within which they work"* |
| American General Association of Contractors | *"Lean Construction is based on the holistic pursuit of continuous improvements aimed at minimizing costs and maximizing value on a construction project, planning, design, construction, activation, operations, maintenance, salvaging, and recycling"* |
| *Lean construction Institute* | *"A respect- and relationship-oriented production management-based approach to project delivery—a new and transformational way to design and build capital facilities".* |

Taking a lead from the lean construction, many of the authors have tried to explain lean design as an approach to remove the wastes and non-value adding activities within the design and engineering processes by applying the principles of lean production (Freire and Alarcón, 2002; Gambetese and Pestana, 2014; Brookfield et al., 2004).

To remove drawbacks of the traditional design management approach, the lean design reinforces the conversion perspective of traditional methods with value generation and flow of information/processes. In a value generation perspective, the emphasis is given in identifying the exact customer requirement. The main principle of this perspective is to eliminate all non-value adding activities/requirements so that the final product is made with the best possible value. Value is carefully analyzed at the very outset by applying rigorous requirement analysis and systemized management of flow. The correct and best possible value is then generated by frequent interactions between all the stakeholders involved both in design and construction.

Visualizing the design as the flow of information/processes is another core concept of lean design. The main emphasis in this perspective is to eliminate the wastes by carefully developing a system in which information is reached to the desired stakeholder with the following characteristics:

- Minimizing the time of retrieving the information between client, architects, engineers, and field investigators
- Correct information all the time thereby reducing the time in evaluating the information as per the conformance
- Reducing the time in reworking on the information for achieving the conformance

In design, the importance of the flow of information has to be realized by all stakeholders. Every stakeholder has to rely on the information from another stakeholder to make the work flowing. Perceiving design as a flow of information necessitates the maximum coordination and collaboration between architects, engineers, contractors as well as supply and specialty subcontractors.

Extensive research has been available in which the theoretical concept of lean design has been elaborately explained however the ways and means by which one can implement the lean design in the construction industry is an area that needs further exploration. At the moment, most of the research in lean design is focused on discussing the individual practices like LPS®, target value and set-based design (TVD/SBD), and the use of building information modeling (BIM) in the design process (Freire and Alarcón 2002; Franco and Pichhi, 2016; Tauriainen et al., 2016; Cousins, 2011). This individuality approach in lean design practices has limited the prospect of the addition of new practices thereby limiting the expansion of the lean design implementation phase. Few researchers have tried to introduce several lean design practices but failed to discuss the efficacy of these practices for events causing the design changes in actual construction (Ballard and Zabelle, 2000; Gambetese and Pestana, 2014; Marzouk et al., 2011).

Theoretically, the lean design is considered to be the solution to many of the design problems prevalent in the construction industry but there is a need to assess the efficacy of this design approach based on the real-time design causes. To fill the gap, this research has been developed considering the following objectives:

1. To identify the best practices for making the design lean
2. To study the efficiency of lean design practices in eliminating the causes leading to design changes in construction

# Methodology

This research will be conducted by employing the extensive literature review in identifying the best lean practices that should be incorporated into the design. The best practices are further mapped with the existing design anomalies to establish the efficacy of each practice in bringing the improvement within the design. The complete schematic description of the research methodology is given in Figure 1. Based on the lean design concepts and principles, improvement zones will be identified for improving the design management processes in construction. For implementing the lean design, lean design practices would then be explored and grouped within their respective zones of improvement. The efficacy of individual design practices is judged based on its capability of combatting the events leading to the design changes.

The final outcome in the form of metrics, indicating the lean design practices applicable for mitigating the respective cause of design changes, will be established. The factual causes of design changes as determined by Aslam et al. (2019) are retained in this study for testing with lean design practices to reduce their effect.

The forums of lean construction institute (LCI) like the international group of lean construction (IGLC) and lean construction journals (LCJ) are considered as the primary resource for selecting the quality journal and conference papers. Apart from LCI, the data banks of Science Direct, American Society of Civil Engineers online (ASCE), and google scholar are also searched for the extraction of papers. Only the quality papers are retained for further analysis based on the three-stage filtration approach proposed by Mok et al., (2015). Out of 183 papers initially selected, only 128 papers fulfilled the final criteria for retention in this study.

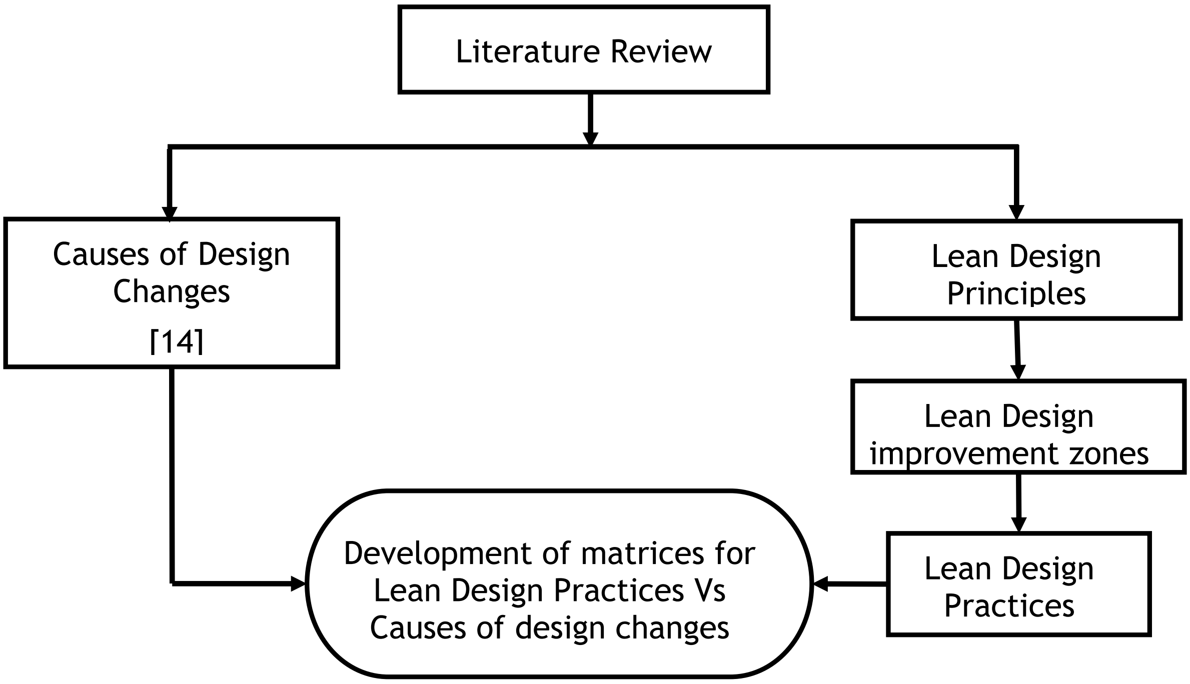


**Figure 1: Research Methodology**

## Lean Design improvement zones and practices

Based on the theoretical explanation of the lean design as explained above, four principles of lean design are selected to bring improvement within the design processes. These principles are the constant and reliable flow of information (Mota et al., 2019; Thibelsky and Sacks, 2010), optimum value generation (Giménez et al., 2019; Khilafe and Hamza, 2019), collaboration among the stakeholder (Mota et al., 2019; Arroyo and Long, 2019) and achieving perfection/continuous improvement (Barth et al. 2019). Apart from these principles, the integration of design with construction (IDC) is also considered to be an important area to be focused on during the design. Yap and Skitmore (2017) have highlighted the design-related constructability issues which can arise due to the lack of skills or resources available within the construction region. Many researchers have also highlighted the disintegration of design and construction as another important area causing the design changes (Austin et al., 2002; Sha'aret al., 2017; Lopez et al., 2010). Based on the above-mentioned literature facts, our research team has further summarized the essentials of the complete lean design process in the form of improvement zones through brainstorming and systematic literature review. These improvement zones contribute towards achieving the principles of lean design and are discovered by many key researchers in the past. All these improvement zones are connected and highly dependent on each other to make efficient design. The summary of the improvement zones within the framework of lean design is shown in Figure 2.

The productivity of lean design depends on the efficient working of all five improvement zones throughout the design phase. This can be achieved by incorporating different lean design practices specifically made to bringing improvements in the respective zones. Different lean design practices identified from different studies and grouped into the respective improvement zones are discussed in the subsequent paragraphs.

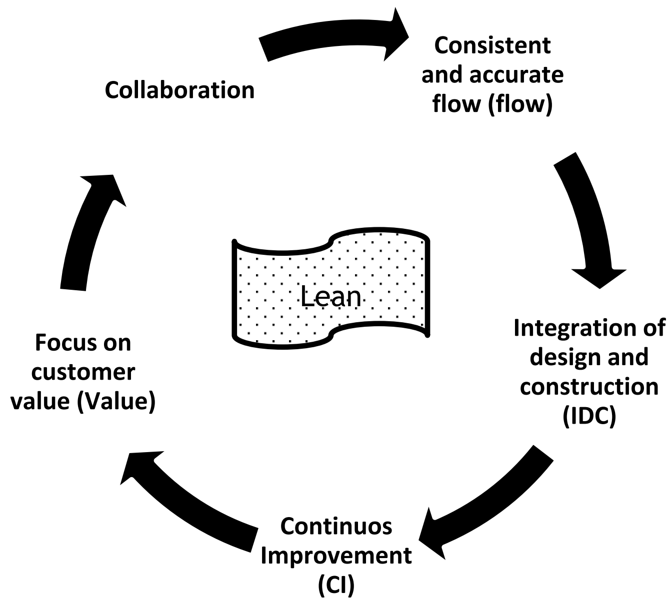


**Figure 2: Lean design perspective**

## Full Collaboration among all the Stakeholders

One of the hallmarks of lean philosophy is considering the complete production processes as one entity in which all stakeholders have the mutual goals of delivering the product in the best possible way and as per the customer's choice (Ballard and Zabelle, 2000; Koskela, 1992; McGraw Hill, 2013). Commitment to achieving the mutual goals from all stakeholders will come from collaboration between themselves. Collaboration among the client, architect, engineer, contractor, and specialty/subcontractor can eradicate many of the prevalent causes leading to the design changes. Clients will be able to educate themselves in terms of technical issues of the product through the timely guidance and supervision of architects, engineers, and contractors. This would decline the design changes resulting from the ignorance of the client on technical issues. The Clients, architects, engineers can be more focused on identifying and delivering the best product through collaboration with each other. One of the major causes of design changes is the lack of communication and coordination between various parties and the oblivious relationships between engineers and contractors (Bibby, 2003; Yap and Skitmore, 2017; Austin et al. 2002). Mutual collaboration can help in resolving such issues. To have a collaborate environment in which all stakeholders are ready to help each other, few lean design practices as recommended are given in table 2:

**Table 2: Lean Design Practices**

| Improvement Zones | Lean Design Practices | References |
|---|---|---|
| Full Collaboration among all the stakeholders (Collaboration) | Meetings, Conferences in a big room by all stakeholders (BR) | (Cousins, 2011; Ballard and Zabelle; 2000, El. Reifi and Emmitt, 2013) |
| | Video Conferences (VC) | (Tauriainen et al., 2016). |
| | Knot working (KW) | (Tauriainen et al., 2016). |
| | Developing a culture of teamwork (TW) | (Ballard and Zabelle, 2000; Gambetese and Pestana, 2014; McGraw Hill, 2014) |
| The consistent and accurate flow of processes and information in the design (Flow) | Integrated Information System (IIS) | (Marzouk et al., 2011) |
| | Frequent communication between the parties (Freq Comm) | (Brookfield et al. 2004; Gambetese and Pestana, 2014; Freire and Alarcón, 2002) |
| | Last Planner System® (LPS®) | (Ballard and Zabelle, 2000; Freire and Alarcón, 2002) |
| | Value Stream Mapping (VSM) | (Jørgensen, 2006; Deshpande et al., 2011; Brookfield et al., 2004; Ballard, Kim, Jang and Liu, 2007; Koskela, Ballard and Tanhuanpää, 1997) |
| | Design Structure Matrix (DSM) | (Rosas, 2013) |
| | Use of 5S | |
| | Deciding at last responsible moment | (Deshpande et al., 2011; Gambetese and Pestana, 2014) |

| Improvement Zones | Lean Design Practices | References |
|---|---|---|
| Focus on customer value (Value) | Target Value Design (TVD) | (Tauriainen et al., 2016; Gambetese and Pestana 2014; Cousins, 2011; Franco and Picchi, 2016; Do, Chen, Ballard and Tommelein, 2014) |
| | Set-Based Design (SBD) | (Melhado, 1998; Ballard and Zabelle, 2000) |
| | Design workshops (DW) | (Emmitt et al., 2005) |
| | Quality function deployment (QFD) | (Kamara, 2003; Ahmed, Sang and Torbica, 2003; Delgado, Bampton and Aspinwall, 2007 ) |
| | Purpose Built Facility (PBF) | (Deshpande et al., 2011). |
| | Building Information Technology (BIM) | (Tauriainen et al., 2016) |
| Integration of design and construction (IDC) | Integrated project delivery (IDP) | (McGraw Hill, 2014; Cousins, 2011) |
| | Virtual Design Construction (VDC)-Building Information Modelling (BIM) | (Deshpande et al., 2011; Franco and Picchi, 2016). |
| | Management of supply chain in the design | (Yap and Skitmore, 2017; Cousins, 2011) |
| | Internet of Things (IoT): | (Dave, Kubler, Främling and Koskela, 2016; Yue Wang, 2015) |
| | Concurrent Engineering (CE) | (Ballard and Koskela, 1998; Tzortzopoulos and Formoso,1999; Rosas, 2013, Akram et al., 2013). |
| | Cross-functional/ Multidisciplinary teams (Cross FT) | (Melhado, 1998) |
| Achieving Perfection in Design Processes (CI) | Lean Audits | (Deshpande, 2011) |
| | Last Planner System® (LPS®) | (Tauriainen et al., 2016) |
| | Transparency | (Marzouk et al., 2011). |
| | Training | (Freire and Alarcón, 2002) |

## Consistent and Accurate flow of processes and information in Design

In the design process, the flow of information has to be very consistent, reliable, and timely. There will be many pieces of information and data handling activities that need to be passed from one design team to another design team. The most important thing in maintaining flow is to deliver the information timely along with eliminating the flow of wrong, out of date and unnecessary information (Marzouk et al., 2011). The accurate flow of information will result in the elimination of many causes of design changes like designer's noninvolvement/unavailability during the construction phase, the inadequacy of information provided to engineers and architects, lack of adequate documentation, unstructured design process, and wrong information provided in the drawings for contractors. The best practices in ensuring the adequacy of the flow of information are as shown in table 2.

## Focus on Customer Value

Value has to be identified through the regular dialogues with clients/owners/customers and keeping in mind the product outputs at specific cost and time (Tzortzopoulos and Formoso, 1999; Koskela et al., 1997; Marzouk et al., 2011). Lean philosophy advocates the value in terms of the client's/customer's perspective whereas architects, engineers, and contractors help them in setting the optimized best value. Every stakeholder should have only one concern that is to deliver the best value to his or her customers/clients. Identification of best value right at the outset of the project initiation through mutual collaboration would result in eliminating the frequent scope changes by the client at later stages, lack of awareness of clients' needs by designer, scope changes due to financial and business changes by client, and unreasonable client's requirements. Identifying the value from the perspective of the Client is not an easy task and requires special commitment and methods, which may vary depending on the client to the client. Few practices are shown in table 2.

## Applying Pull Approach (Pull)

The main purpose of the pull approach is to ensure that preceding activities should not be produced or moved till the time the subsequent activities demands it. This is used to reduce the wastes that are generated due to storage and sorting the activities. In lean design, this is done by scheduling the whole information gathering process backward and ensuring that all information is delivered when there is a right time for its use (Brookfield et al., 2004; Jørgensen, 2006; Ballard and Zabelle, 2000). Jumbling up all the information will forecast two major problems in design: one is that for storing the unused information, a storage mechanism is required, secondly, to extract the information from the storage devices, the considerable effort can be wasted (Marzouk et al., 2011). To overcome these problems, a pull mechanism is used in the lean design for getting the information. The pull approach generally works within the tools like the design structure matrix to eliminate the negative iterations within the complete design process and LPS® to help establish a more structured approach towards design. The use of a pull approach in design will help in minimizing the time of approvals of the drawings as well.

## Integration of Design and Construction

Many of the design changes are due to the lack of practical experience of the architect and engineers in the field of construction (Lopez et al. 2010; Minato, 2003; Yap and Skitmore; 2017). As a result, if the design is solely based on the inputs from designers, there might be many design changes at later stages. Due consideration to the constructability will help in eliminating the causes of designs like designer's lack of awareness about construction, lack of confidence of designers in preplanning for design work, incomplete drawings and plans, contractors request for changing the design due to non-availability of material and construction methodology and strictness on tolerance issues. Some of the practices that can ensure the integration of design and construction are as shown in table 2.

## Achieving Perfection in Design Processes

The perfection is achieved by continuously applying the practices of lean design concepts as explained above and then measuring the outcome of the applied practices. The measured outcomes will be further analyzed for improvements by modifying the practices. It is an endless process to reduce efforts, time, space, cost, mistakes, and all sources of waste while continuing to offer clients what they exactly want. Similarly, new tools and technologies are rapidly emerging to be included in applying the lean design. Many causes of design changes like lack of experience in new construction technologies, lack of knowledge about design standards, governmental regulations, construction bylaws, and inexperience can be eliminated by developing a culture of learning. Few practices suggested for achieving perfection in the lean design are shown in table 2.

# Efficacy of Lean Design Practices for Reducing the Design Changes

To select the lean design practices, the organizations must carry out their internal audit to determine which lean design practice can adjust as per their organizational and project environments. The aim of lean philosophy is not to restrict the user to certain sets of practice but provide them an opportunity to deciding the most desirable lean design that best meets the prevalent situation. In this study, the best lean design practice is identified by using the following procedures.

The first step is to identify the most common causes of design changes hampering the construction project outcomes. Most of the causes of the design changes are already identified in Aslam et a. (2019) and are retained in this study to identify tools that can help in eradicating these causes.

The second step is to categorize all the causes of design changes within improvement zones to see how we can minimize the future occurrence of all these events that are leading to design changes. Another round of literature review/brainstorming was carried out to identify the improvement zones that can prevent future occurrences of design changes events. Each identified cause of design change is explored for finding their most common remedies and further categorized under the improvement zones. As an example, most of the design changes are associated with the lack of the Client's technical knowledge to comprehend and visualize the project. As a result, when construction activities are in progress, and the Client can better visualize the project, they order scope changes to compensate for their initial lack of technical knowledge. In other cases, Architects/Engineers have difficulties both in capturing clients' needs and conveying conceptual design options to them. Such types of design changes occur because of a lack of collaboration and communication between Clients and Architects. If Clients are made well aware of the technical requirements before the construction proceeds or if the Architects/Engineers have fully captured the Client's requirement before designing, such events of design changes would not be happening. So the improvement zones identified for mitigating these two causes of design changes are collaboration and value generation respectively. To validate this, the literature review confirmed that through collaboration and value generation exercises, such type of design changes can be reduced. In the same way, improvement zones are identified for other causes of design changes. Due to limited space, detailed literature references that how improvement zones are identified for every cause of design change are not given in this study however example Table 3 is presented that can show how some of the causes of design changes are categorized into improvement zones.

**Table 3: Examples for categorizing causes of design changes in improvement zones**

| Causes of Design Changes | Suggested Lean practices | Relevant improvement zones | References |
|---|---|---|---|
| • lack of Client's technical knowledge to comprehend and visualize the project | • Participation of clients in the design phase<br>• Use of BIM to visualize<br>• Improving communication between different parties | • Early involvement and collaboration | • Herrera et al., 2019<br>• Reifi et al., 2013<br>• Knotten et al. 2016<br>• Ballard, 2002<br>• Sacks et al. 2020 |
| • Architects/Engineers have difficulties both in capturing clients' needs and conveying conceptual design options to them | • Participation of clients in the design phase<br>• Early involvement of design specialists for the project<br>• Improving communication between different parties | • Collaboration<br>• Customers value | • Herrera et al., 2019<br>• Ballard, 2003<br>• Frieire 2002<br>• Salgin et al., 2016 |
| • Inadequate pre-construction study and review of design documents by contractors considering the exotic and complex nature of design<br><br>• Adversarial/Oblivious relationship between consultant and contractor | • Involvement of builders/contractors during the early design stages of the project.<br>• Managing flow of information by involving contractors early<br>• Simultaneously design of the product and the construction process<br>• Improving communication between different parties | • Collaboration<br>• Flow management<br>• Integrated design and construction (IDC) | • Ballard et al, 2002<br>• Formoso et al., 1998<br>• Sodal et al., 2014<br>• Ballard, 2002 |

In the last step, the improvement zones are mapped against the best lean design practices. From the systematic literature review, we have identified the respective lean design practices that can target the respective improvement zones and are already shown in Table 2. In case the improvement zone is collaboration, tools like BR, KW, Freq comm, IDC and VDC can be the lean tools that can be employed to increase collaboration. For the sake of simplicity many practices that are sequential or having many common characteristics have been grouped. Moreover, many practices can be an integral part of another practice if applied in full spirit. For example, teamwork, reverse phase scheduling, transparencies, and decision deferred until the last responsible moment are inherent in the LPS®. Knot working and big rooms are combined because of the same objective of achieving better collaboration. Since the SBD and TVD are interlinked, in which design alternatives are checked against the targeted cost, hence kept in the same group. Design workshop and quality functional deployment are grouped as both are used for identifying the exact requirements of the clients.

Finally, we developed a matrix that can show how the construction industry can use different lean design practices to eradicate the events leading to design changes in Table 4.

## Practical Contribution of the developed matrix

The developed matrix as shown in Table 4 has plenty of useful pieces of information that can be used by the Construction Industry and new lean practitioners to improve their design practice. It can be used by Clients, Architects/Engineers, and contractors to identify the best lean practices that can lead them to better design management. Since the matrix is developed based on the most common causes of design changes, therefore it can be employed on any type of project. If a Clients or Architects/Engineers or Contractor is repeatedly encountering project delays and cost overrun due to frequent design change, he/she can identify the areas that need to be improved to eradicate the design changes issues. As an example, the frequent scope changes can be decreased by the early involvement of all major stakeholders through collaboration, value engineering exercises, and integrated design and construction (IDC). The recommended tools that can enable these improvement zones are BR, Freq Comm, VSM, IIS, TVD/SBD, QFD, and IPD. There might be a possibility that companies have developed integral tools other than mentioned in Table 4 to increase collaboration, value, and integration of design and construction like an Integrated form of agreements (IFOA), partnership, etc. They can update the matrix based on their best tools. In summary, Table 4 can provide the basic start point to the stakeholders for managing the design process through lean practices. However, it can be further developed based on the Companies requirement.

## Table 4: Suggested Lean Practices Vs Causes of Design Changes

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| **Client Related** | | | | | | | | | | | | | | | | | | | | | | | |
| Lack of technical knowledge to comprehend and visualize the project | * | | | | | * | * | | | | | | | | | | | | * | | | * | |
| Lesser guidance and support available to Clients by technical persons | * | | * | | | * | * | * | * | * | | | | * | * | * | | | * | | * | * | * |
| Frequent scope change by the Clients | * | | * | | | * | * | | * | * | | | * | * | * | * | | * | * | * | * | | * |
| Long-time taken by the client for giving decision | | * | * | | | | * | | | * | | * | | * | | * | | | * | | | | |
| Clients changing financial and business conditions necessitates the scope changes | * | | * | * | | * | * | | * | | | * | | * | * | * | | | | | | | |
| Inappropriate choice of project contract type (unit price, lump sum, etc.) | * | | | * | | * | * | | | | | | | | | * | | | | | | | |

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| Unreasonable Client and End User Expectations | * | | * | | | * | * | | * | * | | | | * | * | * | | | | * | * | | |
| **Architect/Engineer Related** | | | | | | | | | | | | | | | | | | | | | | | |
| Designers lacked the awareness of design to provide commercially focused solutions and constructability | * | | | * | * | * | * | | * | * | | | | * | * | * | | * | * | * | * | * | |
| Lack of confidence in preplanning for design work | * | | | | * | * | * | | | | | | | | | | | | | | * | * | |
| Designers have difficulties both in capturing clients' needs and conveying conceptual design options to them | * | | * | | | * | * | | | * | | * | * | * | * | * | | | | | | | |
| Deficient resources in quality or quantity (e.g. tools, equipment, staff, or financial) | * | | | * | * | * | * | * | | | | | | | | * | | * | | | | | * |
| Poor coordination and communication | * | * | | | | * | * | | | * | | * | | | * | * | | | | | * | | |

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| between Client and designer as well as designer and contractor | | | | | | | | | | | | | | | | | | | | | | | |
| Lack of information flow among parties | | * | | | | | * | * | | * | * | * | | * | | | * | | * | | * | | |
| Unstructured Design process | | * | | * | | | | * | | * | | | | | * | | | | | | | | |
| No Design checking or 2nd or 3rd party reviews, No system of design checking | | * | | | * | | * | | | | | | | * | | * | | | * | | * | * | * |
| Ineffective utilization of automation | | | | | * | | | | | | | | | | | | * | | * | | | | |
| Time Constraints | * | | | * | | * | * | | | * | * | | | | | * | | | | * | * | | |
| Designer noninvolvement/unavailability during the construction phase | * | * | | * | | * | * | | | | | | | | | * | | | | * | * | | |
| Inadequate information provided to Designer | * | * | | | | * | * | * | | * | | * | | * | * | * | * | | * | | * | | * |

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| The short-term conflict between productivity (production) and quality. | * | * | * | | | * | * | | | * | | | | * | | * | | | | | | | |
| Inadequate training/ inexperience, lack of knowledge in ( building bye-laws, codes etc, constructability, availability and suitability of materials, engineering design techniques | | | | | * | | | | | | | | | | * | | | | | | | * | * |
| Change of designers | * | * | | | | * | * | | | * | | | | * | | * | | | | | | | |
| Lack of Design Standards. | | | | | * | | | | | * | * | | | | | | | | | | | | |
| No involvement of contractor during the design phase | * | * | * | * | | * | * | * | * | * | | | | * | * | * | | * | * | * | * | | |
| Lack of adequate documentation | | * | | | * | | | | | | * | * | | | | * | | | | | | | * |
| Late approvals of design | * | * | | * | | * | * | | | * | | | | | | * | | | * | | * | | |

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| Several groups visit project late and give their points too late | * | * | | * | | * | * | | | * | | | | | | * | | | | | * | | |
| Discrepancies between contract documents | * | * | | * | | * | * | | | * | | | | * | | * | | | | * | * | | |
| **Contractor Related** | | | | | | | | | | | | | | | | | | | | | | | |
| Inadequate pre-construction study and review of design documents by contractors considering the exotic and complex nature of design | * | * | | * | | * | * | | | * | * | * | | * | * | * | | * | * | * | * | | |
| Awarding contract to the lowest price regardless of the quality of services | | | | * | | * | | | | * | | | | | | * | | | | | | | * |
| Lack of experience in new construction technologies | * | | | | * | * | | | | | | | | | | | | | * | | * | * | |
| Lack of communication and coordination | * | * | | * | | * | * | | | * | | * | | | * | * | | | | | * | | |

| Identified causes of Design Change | Improvement Zone | | | | | Suggested Lean Design Practice | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Collaboration | Flow | Value | IDC | Perfection/CI | BR/KW | Freq Comm | DSM | VSM | LPS® | 5S | IIS | Pull | TVD/SBD | QFD/ Design Workshop | IPD | IOT | Supply chain in design | VDC-BIM | CE | Cross FT | Training | Lean Audit |
| between the various project team | | | | | | | | | | | | | | | | | | | | | | | |
| Information problems | * | * | | | | * | * | | * | * | * | | * | | | * | | * | | * | | | |
| Adversarial/Oblivious relationship between consultant and contractor | * | | | * | | * | * | | | * | | | | * | * | * | | | | | * | | |
| Shop drawings' submission, approval and adequacy | | * | | | | | | | | * | | * | | | * | * | | | * | | * | | |
| Contractors request on improving the buildability by suggesting alternate construction method and material used | * | * | * | * | | * | * | | * | * | | | | * | | * | | * | * | * | * | | |
| Strict quality tolerances mentioned in the specification | * | * | | * | | * | * | | | * | | | | * | * | * | | | * | | * | | |

## Findings and Discussions

In this study, an effort has been made in considering lean design practices, which can be used as an effective tool in reducing the design changes. Many design discrepancies occur because of undefined customer's requirement at the initial stages. Lean design advocates in identifying the exact and best value of the customer's requirement by duly incorporating the architects, engineers, and contractor's views in providing the best knowledge to the customers. Identifying the correct value at the early stage will definitely eradicate many scope related design changes in the future. The summarized representation as shown in Figure 3 shows that nine causes of design changes are due to the wrong or undefined value from the client.

Errors and omissions in the design are another significant cause of rework. Errors and omissions in the drawing, plans, and specifications occur because of lack of accuracy in information, poor knowledge, information not received at the right time, information not interpreted in the right way, and no mechanism of checking the drawings by another party. Lean design is one of the strongest proponents of considering the flow of information as an important component of the design process. It will reduce the wasteful activities within the design and ensures that accurate information is delivered on time to the right person at the right time. 20 causes of design changes are because of discrepancies in the flow of information as shown in Figure 3. As seen in Figure 3, the causes of design changes falling under the improvement zones of collaboration, flow, IDC, and perfection are 27, 20, 17, and 9 respectively. The number of causes of design changes is obtained by adding all the causes of design changes under the specific improvement zone as mentioned in Table 4. We can say that it is the summation of respective columns under the respective improvement zones.

Two important aspects of design processes, which must be taken into account, are the integration of design with construction and continuous improvement within the developed lean design processes to achieve perfection. The integration of design with construction requires a complete collaboration by all the parties of the contract including the specialty and supplier's subcontractors. Lean design enforces the involvement of contractor, supplier, and specialties subcontractors early in the design stage to evaluate the drawing and plans based on its constructability. This will remove the conflicts between design and construction in terms of drawings, material availability, complexities, and methodologies.

Based on the results as shown in Table 4, lean design practices like freq comm, IPD, BR/KW, LPS®, and cross-functional teams can be most effective in reducing more than 20 causes of design changes respectively. This entails that collaboration and communication between all the stakeholders are essential for effective design. The use of LPS® and IPD can also help in targeting 26 and 29 causes of design changes respectively. Pull approach, look ahead plans, weekly plans, and integrated approach of design and construction in a collaborated environment are the key components of LPS® and IPD. The use of BIM and TVD/SBD can significantly reduce the number of causes of design changes, 16 and 18 respectively. The complete summary showing the number of causes of design changes effected by each lean design practice is given in Figure 4. Again the number of causes of design changes is obtained by adding all the causes of design changes under the specific lean design practices as mentioned in Table 4. We can say that it is the summation of respective columns under the respective lean design practices.

Different lean design practices as mentioned in Figure 4 can provide a guideline for construction firms, owners, or consultants to start with the lean design approach. Lean philosophy never advocates on restricting to one or two practices rather it promotes a culture of innovation and creativity in which best practices that best suit the prevailing circumstances/environments, are selected.

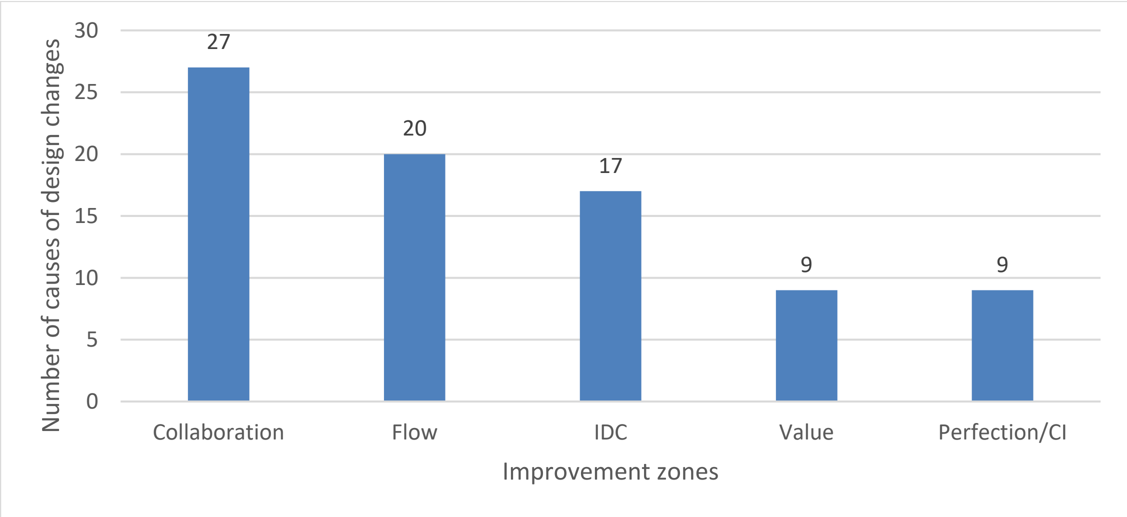


**Figure 3: Categories of causes of Design Changes within Respective Improvement Zones**

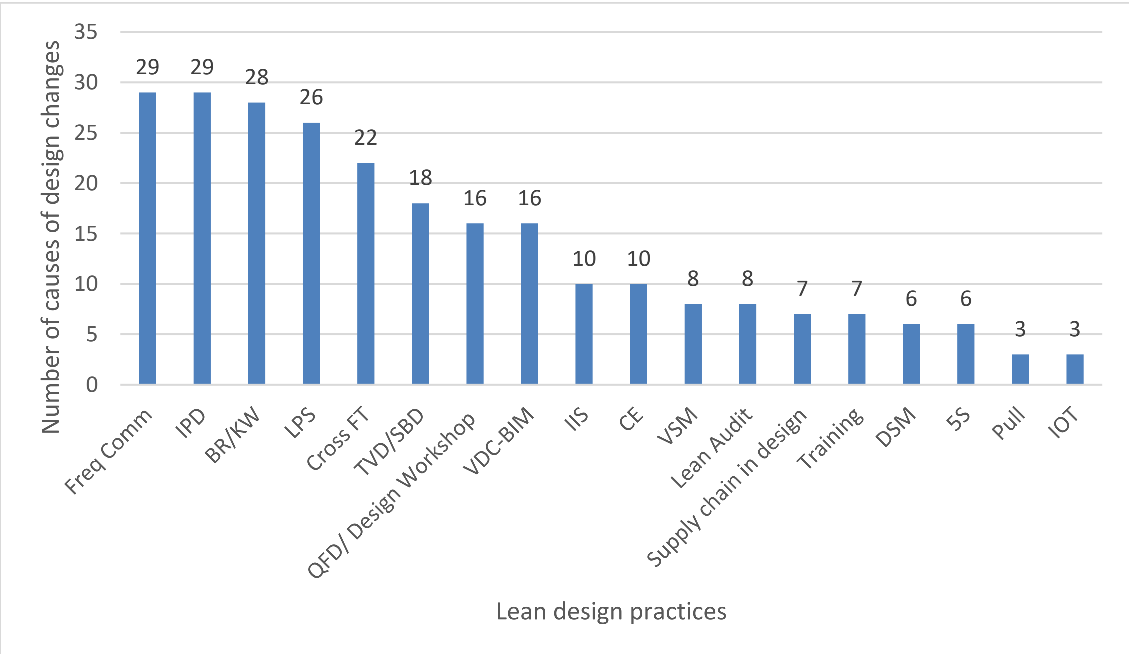


**Figure 4: Lean Design Practices Targeting causes of Design Changes**

## Conclusions

Application of lean design practices during the design phase will eventually lead to the reduction of design changes that normally occur at later stages in construction and having detrimental effects on the cost, time, and productivity. Many events lead to design changes like errors and omissions and result in rework or additional works. Lean literature has suggested several lean design practices that can be used to target these causes of design changes. A very elaborative study is carried out in determining the lean design practices which are further mapped based on their role in targeting the respective causes of design. This approach has provided a more distinct role of each practice in eliminating the causes of design. Since the causes of design changes are summarized based on the most commonly encountered causes of the design changes on construction projects as documented in the existing literature, thereby making the findings of this study more realistic and close to the construction project environments. The role of Clients, architects, engineers, and contractors in eliminating the design changes can only be effective if these stakeholders work together as a team in a mutually collaborative environment which is the basic hallmark of lean construction philosophy. The inculcation of flow and value views within the design processes leads towards a more structured approach towards design with the reduction of inherent wastes within design processes and information. The outcome of this study will provide a systematic approach to the construction industry and new lean practitioners for making the design process as efficient as possible by using lean design practices. Additionally, the developed matrix will be very helpful to the new lean practitioners in finalizing their lean tools and techniques during the design phase. In further continuation of this study, it would be a great assistant to the construction industry if a complete framework is presented in future research for implementing the lean design practices during different stages of design and validating the results from its actual application in real-time construction projects.

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