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Development of Leanness Assessment Index (LAI) for Performance Evaluation of Building Construction: A Case Study of a Surat City

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ABSTRACT- Lean construction is a "way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value". Compared with mass production, lean production employs fewer resources, such as manufacturing plant, space, time, investment, design activities, and on-site inventory level to deliver a similar product with the same level of quality in the most economical and efficient manner. Leanness index provides a direction to eliminate or at least reduce manufacturing wastes during the implementation of lean strategies towards continuous improvement. The leanness measure models provide a tool to track, assess, and compare the leanness level of the organization during lean manufacturing transformation. All performance measures were assumed equally important, and the relationships between lean performance metrics were not considered in the reviewed literature. Therefore, there is a gap in the literature to investigate strategies to priorities different performance metrics according to competitive strategies and manufacturers' requirements and include the interrelationship between lean performance metrics in the current leanness assessment models. This can increase the accuracy of the leanness assessment approach and reflect the manufacturers' needs in the overall leanness score.

Keywords: Lean construction, Construction waste, Leanness index, Lean performance matrix

I. INTRODUCTION

In today's competitive market, manufacturing firms are facing tremendous pressure on customer's expectations about product quality, demand responsiveness, reducing cost, and product variety. To meet with such expectations of the customer's production industry is striving for modern manufacturing initiatives and lean manufacturing is one of the best initiatives in that direction. Lean manufacturing as a multi-dimensional approach that encompasses a wide variety of management practices, including just in time, total quality management (TQM), work teams, cellular manufacturing, Supplier involvement, etc. in an integrated system. Lean refers to those process which results in maximum value through minimum consumptions of resources. Compared with mass production, lean production employs fewer resources, such as manufacturing plant, space, time, investment, design activities, and on-site inventory level to deliver a similar product with the same level of quality in the most economical and efficient manner (Womack and Jones 1990; Bayou and Korvin 2008; Anvari et al. 2011).

In addition, according to Shah and Ward (2007), lean production is an integrated socio-technical system that eliminates manufacturing wastes and controls the variability of suppliers and customers. Leanness index provides a direction to eliminate or at least reduce manufacturing wastes during the implementation of lean strategies towards continuous improvement. It also indicates the improvement achieved during the lean journey (Papadopoulou and Özbayrak 2005; Anvari et al. 2011). According to Wan and Chen (2008), the leanness is the streamlined performance level in comparison with the optimum level (Wan and Chen 2008). It is believed by many that the reason for the failure of many of the current lean implementation practices is the lack of an appropriate method to measure and monitor the leanness levels before and after the implementation of lean strategies. Thus, the leanness measure models provide a tool to track, assess, and compare the leanness level of the organization during lean manufacturing transformation (Soriano-Meier and Forrester 2002; Behrouzi and Wong 2011).

To measure the leanness score of the organization, several research studies identified factors for assessing leanness. These factors reflect the quality or quantity of the production process. Linguistic terms are used to evaluate the qualitative factors, and numerical terms are used for quantitative factors. Some research studies considered qualitative metrics to measure the leanness level (Vinodh and Chintha 2010, 2011; Taj and Morosan 2011; Vimal and Vinodh 2012) and some others used quantitative factors in their methods

(Wan and Chen 2008; Amin 2012). All performance measures are assumed equally important, and the relationships between lean performance metrics were not considered. Therefore, there is a gap in the literature to investigate strategies to priorities different performance metrics according to competitive strategies and manufacturers' requirements and include the interrelationship between lean performance metrics in the current leanness assessment models. This can increase the accuracy of the leanness assessment approach and reflect the manufacturers' needs in the overall leanness score.

Despite so many benefits of lean and its tools, there are several observations that either lean is not implemented in many of the construction sites or if it is implemented it has not much effect as it has in other industries. The reason for that is the barriers to lean implementation in the construction industry. In this study, an attempt is made to create one index using barriers of lean, which can measure the leanness of the construction site. so, it will give the idea weather lean tools can be effectively implemented or not and if it needs to be implemented effectively which things need to be taken care of and what changes are needed into the process of construction work.

II. LITERATURE REVIEW

2.1 Lean Concept

Construction projects are well known for being over budget, late and burdened with scope creep facing a decline in profit margins, and increased competition. Figure 1 shows the "Scope Triangle" which illustrates the relationship between the three tradeoffs in a project cost, time & quality. Successful project management can be achieved by bringing together the tasks and resources necessary to accomplish the project objectives and deliverables within the specified time constraints and within the planned budget.

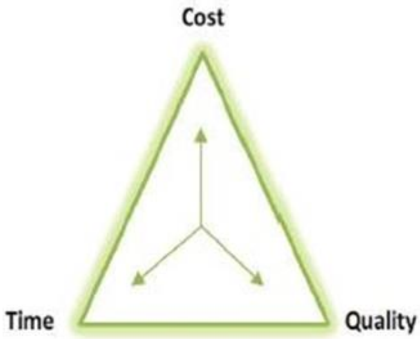


Figure 1 Scope of Triangle

In 1992, Koskela introduced the idea of understanding construction as a production process. Lean production was developed by Toyota led by Engineer Ohno. The actual term Lean was coined by one of the researchers involved in the study which was the basis of the book "The Machine that Changed the World, The story of Lean Production", Womack, Jones, and Roos in 1990 (Holweg, 2007). By eliminating wastes and maximizing the activities that will give value to the client, the best results will come out. In short, one can say that Lean is to "Do Less for More Value" (Simons and Mason, 2003).

Waste has a broader interpretation in Lean than the physical wastes that are the Focus of construction site activity. In fact, waste is any activity (or inactivity) that does not add value to the product or service.

Value-adding (VA): This work changes the shape or nature of the product in a way that contributes to the final form that the customer is willing to pay for.

Essential non-value adding activities (ENVAs, or support activities): these are the tasks that must be completed to enable the value-adding activity to be completed but do not add value. For example, the inspection does not add actual value but is necessary up to the point where a process can be improved so that inspection can be eliminated.

Waste: This is any other activity or event associated with carrying out a particular work activity. Waste can be viewed from two perspectives: Waste in the work itself (e.g. excessive walking, looking for tools and materials, poor quality). Introduced or 'enforced' waste (e.g. waiting for information, materials not supplied), which has prevented work activity from being carried out. Waste exists in different forms, including overproduction, waiting, unnecessary movement, carrying unnecessary inventory, and rework (Womack & Jones, 2003).

Based on the literature of Lean waste and perception the wastes are categorized which are described in Table 1.

Table 1 Lean construction waste

Lean construction waste	Waste specification
Transportation	• Moving, work-in-process from place to place-etc. delivering equipment, incomplete orders. • Unnecessary transportation due to miscommunication. • Moving to and from storage.
Inventory	• Excess raw material, WIP, or finished goods causing longer lead times. • Large site stores of materials. • Poor stock management.
Motion	• Unnecessary movement of people and equipment that does not add value, including walking between different workplaces, etc. • Walking between workplace and welfare facilities, manual paperwork processing. • Movement of materials and drawing information. • Movement of Equipment.
Waiting /delay	• Waiting due to the preceding activity was not completed. • Workers unable to do value-creating work, and capacity bottlenecks. • Waiting time between processes or for the capacity to take the next step. • Documents awaiting updating or processing equipment downtime. • Delay due to supervision
Over-processing	• Taking unnecessary Activity • Work repeating due to miscommunication. • Inefficient processing, especially due to poor design or work planning causing something unnecessary • Providing higher quality products than necessary, and produced to standards beyond specifications (BS).

	• Work was done to 'fill the gaps' rather than appear to be waiting
Over-production	• Larger than necessary excavations, orders placed for the same materials with different suppliers. • Generating waste through overstaffing, storage, and Transportation cost.
Defects	• Rework / Defective works / Corrections / not meeting specifications. • Wrong information on drawings • Defect due to poor mixing and placing of material
Skill Misuse	• Losing time and ideas, skills improvements, and learning opportunities, etc. • Limited authority and responsibility • People working one or two levels down from their true capability.

2.2 Lean Barriers

Previous studies on the barriers to the implementation of lean construction in the construction industry can be categorized into those carried out in developed countries (four) and in developing countries (six). This may suggest that, globally, the barriers to the implementation of lean construction are more pervasive in developing countries, especially those in Africa. The first study was carried out in the construction industry in Singapore among medium to large contracting firms (Dulaimi and Tanamas, 2001), and a significant barrier identified was the unwillingness of the management in contracting firms to train their workers about lean construction techniques, which is also linked to legislative bottlenecks against the training of workers, especially foreign workers in the country.

It is possible that barriers to the implementation of lean construction may be different from the point of view of non-managerial-level respondents or employees/workers in construction organizations in the Ugandan construction industry. Further, similar to the UK construction industry, the greater onus lies in the management of the construction organizations to commit more financial resources and managerial responsibility towards the implementation of lean construction in the Ugandan construction industry. The barriers to implementing lean construction in the Ghanaian (Ayarkkwa et al., 2012) and Libyan (Omran and Abdulrahim, 2015) construction industries are no different from those of other developed and developing countries.

Likewise, the barriers to implementing lean construction in smaller construction organizations in India (Devaki and Jayanthi, 2014) are similar to those in larger construction organizations in other countries such as Uganda. In contrast to the UK, in China, Shang and Sui Pheng (2014) found government-related issues such as stringent requirements and approvals to be barriers to the implementation of lean construction. Similarly, Olamilokun (2015) revealed that corruption and/or corruptive tendencies from government agencies is a barrier to the implementation of lean construction in Nigeria. And similar to the Singaporean construction industry (Dulaimi and Tanamas, 2001), Shang and Sui Pheng (2014) found adversarial relationships and/or lack of cooperativeness among construction professionals to be a barrier to the implementation of lean construction in the Chinese construction industry.

2.3 Lean Tools

After analyzing papers of lean waste and lean perceptions papers related to Lean tools have been studied to find out the practical implementation of lean tools in the construction industry and what the advantages of those lean tools are and how they help the construction industry to enhance their performance. After analyzing, the papers related to Lean tools and its application in construction all the lean tools have been classified under the following:

a) Schedule mapping tools,

b) Quality Improvement tools,

c) Continuous improvement tools,

d) Waste reduction & Safety tools

Table 2 Lean tools for scheduling

Author (s)	**Lean Tools/Techniques**	**Use**
Rahman et al. (2012), Muhammad et al. (2013), Aziz and Hafez (2013)	The Last Planner System (LPS)	• It will be used to achieve lean goals, reducing waste, better productivity. • It deals with various variability in projects
Rahman et al. (2012), Leanproduction.Com (2015)	Value Stream Mapping (VSM)	• A technique for visually analyzing, documenting, and improving the flow of a process in a way that highlights improvement opportunities.
Rahman et al. (2012), Muhammad et al. (2013), Aziz and Hafez (2013), Alireza and Sorooshian (2014)	Just in Time (JIT)	• This is a technique aimed primarily at minimizing flow times within a production as well as response times from suppliers and to end-users. • In any case, JIT is a way of thinking, working, and managing to eliminate wastes in processes.

Table 3 Lean tools for quality improvement

Author (s)	**Lean Tools/Techniques**	**Use**
Muhammad et al. (2013), Alireza and Sorooshian (2014)	Standardized Work	• It is used for performing specific construction process based on the available evidence.
Alireza and Sorooshian (2014), Rahman et al. (2012), Muhammad et al. (2013)	The 5S Process	• It is used for better productivity, improving work efficiency, and productivity.

Alireza and Sorooshian (2014)	Kaizen	• It is the Japanese word for continuous improvement of the process. • It improved the time and better use of available resources.
Alireza and Sorooshian (2014)	Total Productive Maintenance (TPM)	• This is a holistic maintenance approach for equipment in order to maximize the operational time of the equipment.
Tsao et al. (2004), Muhammad et al. (2013)	The Five Why's	• This is a quality management tool for problem-solving and it tries to find the root cause of an issue. • It stipulates that workers should be asking why five times repeatedly until they identify the underlying root or the nature of the issue and its solution becomes clear.
Aziz and Hafez (2013), Rahman et al. (2012)	Concurrent Engineering	• This methodology involves the various tasks parallels executed multi- disciplinary teams with the aim of optimizing engineering cycles of products for efficiency, quality, and functionality.
Muhammad et al. (2013), Alireza and Sorooshian (2014)	Error Proofing (Poka- yoke)	• Poka-yoke is a Japanese word, which can be defined as "error proofing".
Alireza and Sorooshian (2014), Rahman et al. (2012)	Six Sigma	• Sets of tools and techniques for improving quality through identification and removal of defects and reduction of variability in processes. Six Sigma is able to achieve the process quality of 99.99966% that is free from defects.

Table 4 Lean tools for continuous performance improvement

Author (s)	**Lean Tools/Techniques**	**Use**
Rahman et al. (2012), Muhammad et al. (2013), Alireza and Sorooshian (2014)	Increased visualization	• This is an information communication technique employ to increase efficiency and clarity in processes with visual signals.
Salem et al. (2005), Muhammad et al. (2013)	Daily Huddle Meetings	• It is used to encourage the employees together. • It achieves employee involvement by arranging daily huddle meetings.

Salem et al. (2005), Rahman et al. (2012), Muhammad et al. (2013)	First, run studies	• It is utilized for remodeling important tasks. • Ideas and suggestions are raised to explore alternative ways of doing the task.
Alireza and Sorooshian (2014)	Time and Motion Study	• A procedure for evaluating industrial or another operational efficiency on the basis of the taken or needed time for an operation or production.

Table 5 Lean tools for waste reduction

Author (s)	Lean Tools/Techniques	Use
Salem et al. (2005)	Fail-Safe for Quality and Safety	• This lean construction tool ensures no harm to specific failures.
Rahman et al. (2012), ASQ (2015)	Muda Walk	• Muda is a Japanese word meaning waste. Muda walk is a technique used to identify waste through observation of operations, how work processes are conducted, and noting areas where improvements are needed.

III. OBJECTIVE OF THE STUDY

In order to achieve the aim following objectives are defined and achieved in this study:

- To develop an evaluation process to obtain Leanness Assessment Index (LAI)
- To formulate and evaluate Leanness of construction sites

IV. METHODOLOGY

To fulfil the aims and objectives, the following phases have been planned:

- **Phase 1:** Three-level hierarchical structure used for finding out weights of barriers and sub barriers of lean. Weights are found using AHP of MCDM.
- **Phase 2:** Leanness rating score for sub barriers are created and which are validated to check their accuracy and after proper feedback required modification is done into rating score and those scores are used for further analysis.
- **Phase 3:** Index of main barriers is found using the TOPSIS method. The rating score is defined, the rating of each sub barriers is found, and those ratings are used to get the index of main barriers.

V. LEAN CONSTRUCTION

5.1 Key Principles of Lean Construction

There are five lean principles, which are described below:

a) Specify Value: The customer-focused approach that can best be achieved by building a relationship with the client. In lean construction, it includes all stakeholders: owner, architect, engineers, general contractor, subcontractors, and suppliers.

b) Identify the Value Stream: All of the actions that are required to deliver the project are defined and mapped. This includes labor, information, materials, and equipment needed for each activity. Any steps in a process that do not add value to the client should be eliminated.

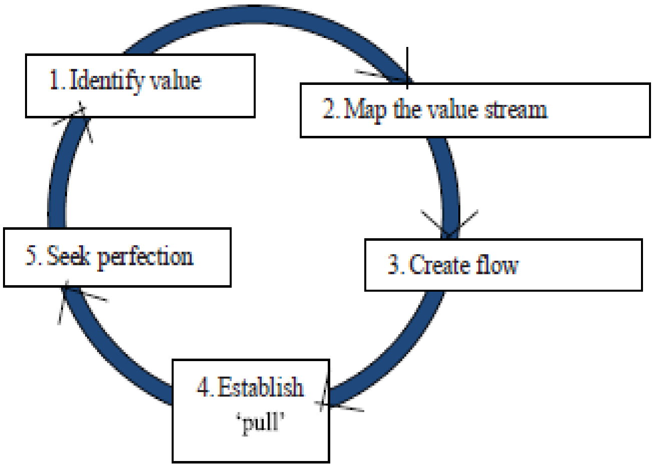


Figure 2 Lean Construction Principles

Source: lean enterprise institute (2009)

c) Flow: Lean construction is accomplished by cutting out waste. The eight major types of waste in construction are easy to remember because they result in DOWNTIME. They are Defects, Overproduction, Waiting, Not Utilizing Talent, Transport, Inventory, Motion, and Excess Processing.

The goal of lean construction is to achieve a continuous workflow that is reliable and predictable. Job site flow includes the activities and the way that these activities should be managed.

d) Pull: Produce only when the client wants the product; let the client "pull" it from you. In lean construction, pull planning is done by those performing the work, typically the subcontractors, through communication and collaboration with each other to dictate the schedule of tasks.

e) Pursue perfection through continuous improvement: Go through the project to see what could have been improved and take that knowledge with you to the next project.

5.2 Steps of Effective Implementation of the Lean Construction

There are several steps, which must be followed for the proper and effective implementation of lean which are discussed below,

a) Split work packages to smaller tasks with reduced variability and less simultaneous work to reduce cycle time.

b) Set up the layout of the worksite to achieve a seamless workflow, clean up, and organize the work site daily using 5S techniques.

c) Reduce changeover from one task to another and prevent machine and equipment failures.

d) Balance work resources (add/remove resources) based on workflow,

e) Arrange resources for all work packages, useless internal logistics implement multi- tasking and cross-training.

f) Use buffers (cost, time, capacity, space, etc.) to absorb workflow variability.

g) Release tasks from one station/worker to another, when required and all resources are ready, preceding tasks are completed, and simultaneous tasks are synchronized.

h) Proceed until the project is completed and delivered to the client. Check the overall Quality, Schedule, and Cost performance and document best practices and lessons learned.

VI. DATA COLLECTION

6.1 Study Area

There are three sectors of construction: buildings, infrastructure, and industrial. Building construction is usually further divided into residential and non- residential (commercial/institutional). In this study, the focus is only made to the residential type of buildings in the Surat region, as there are so many ongoing constructions works of buildings in Surat, which faces issues of productivity, cost overruns, and time overruns. Therefore, to overcome that issue lean implementation is very much crucial. In addition, before implementing lean it is very essential to know about whether it is feasible to implement the lean on a particular site or not, because if we implement it without knowing it lean will not have much impact on the performance of the site.

6.2 Research Design and collection of data

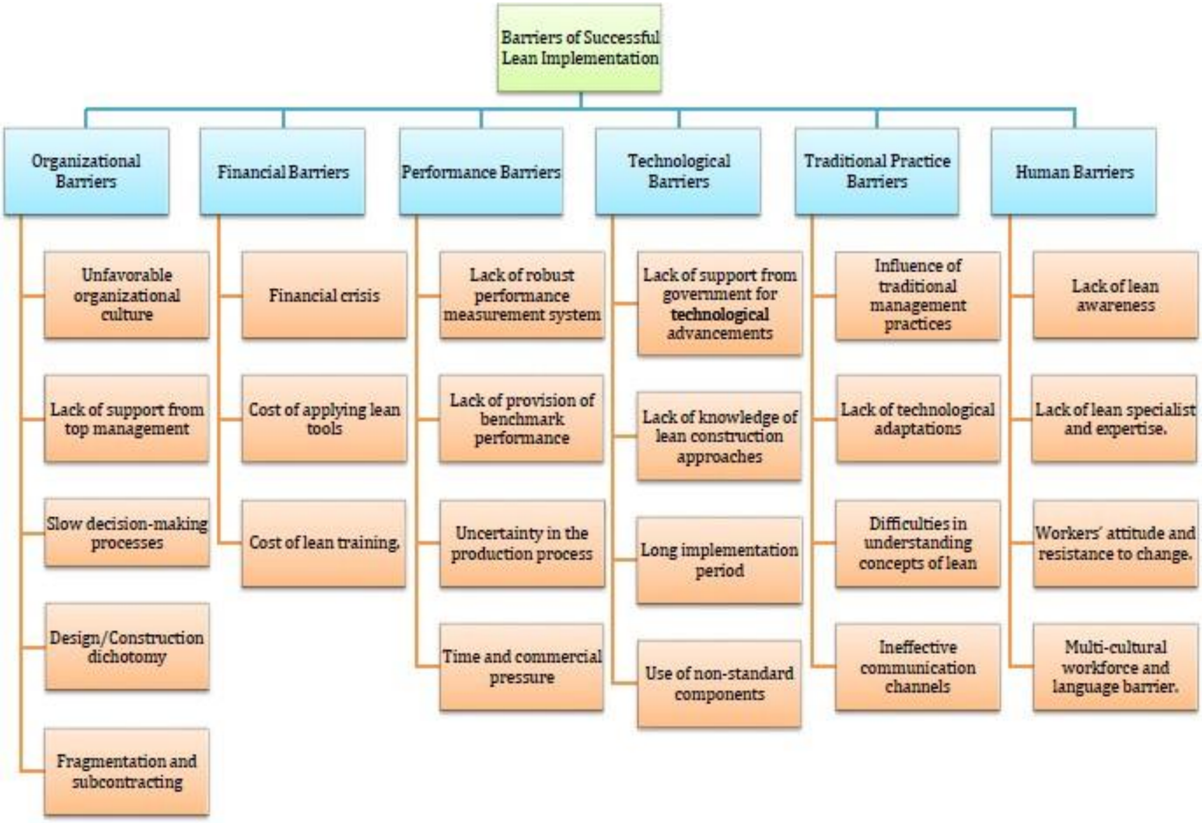
To achieve the defined aim and objectives, the following research methodology is designed and adopted in the study. The research methodology follows four-stage, which are depicted in Fig. 3. After completing all the four-stage we will have LAI that is a leanness assessment index which will help us to identify the leanness score of a particular site. If the leanness index is high, it will say that on that particular site, lean tools can be successfully implemented and it will show a good result. In addition, on the other hand, a low leanness index will say that on that site lean tools cannot be properly implemented or if it will be implemented it will not have much more impact on the performance enhancement of the construction site.

- Stage: 1- Evaluation of weights ofmain and sub barriers using AHP
- Stage: 2- Determine leannessrating score for barriers
- Stage: 3- Computing indexof barriers using Topsis
- Stage: 4- Applying WSM for development of leanness index (LAI)

VII. RESULT AND DISCUSSION

hierarchical structure of lean barriers which was used is shown in Figure 3.

Figure 3 Final hierarchical structure of lean barriers



Measurement of relative weights at the second and third level of hierarchical structure (using AHP)

AHP is used to evaluate the weights of the main and sub barriers. Therefore, the opinions received from each of the 15 experts are fed into Microsoft Office Excel (2016). Then, as recommended in the seven-step process, first the CRs for the experts *E1*, *E2*, ..., *E15* are evaluated and it is found that for some of the experts, the CR exceeded the limit of 0.10. Thus, as suggested by Saaty (1986), a combined matrix of 15 experts is prepared. For example, in comparing organizational and financial barriers, the responses obtained from the experts *E1*, *E2*, ..., *E15* are 1/2, 1/4, 4, ..., 6 respectively. Similarly, the value for comparing the remaining barriers is also obtained.

Then, the CR of the experts *E1*, *E2*, ..., *E15* are computed and found 0.0924, 0.3635, 0.2977 ..., 0.2638 respectively. After that, the value for a cell in the combined matrix of comparing organizational and financial barrier as shown below.

$e_{ij} = [(1/2)^{0.9076} \times (1/4)^{0.6365} \times (4)^{0.7023} \times \cdots \times (6)^{0.7362}]$ ^ $(1/0.9076+0.6365+0.7023+......+0.7362)$

= 0.7842

Where *w1*, *w2*, ..., *w15* are priority weights obtained by 1 - CR. Similarly, rests of the cell of the combined matrix are computed and they are given in Table 6. Finally, the relative weights, λmax, CI, and CR for the combined matrix of the main barriers are obtained and presented in Table 7 while. The relative weight for the combined matrix is presented in Table while the λmax, CI, and CR are 6.076, 0.015, and 0.014 respectively. Similarly, the relative weights of sub barriers are also evaluated and shown in Table 8.

Table 6 Combined matrix

	Organizational	Financial	Performance	Technological	Traditional Practice	Human
Organizational	1.0000	0.7842	2.2059	1.6638	2.0121	1.5853
Financial	1.2752	1.0000	2.7484	3.1021	2.1326	1.7714
Performance	0.4533	0.3638	1.0000	1.2223	0.6261	0.9131
Technological	0.6010	0.3224	0.8181	1.0000	0.9866	0.7205
Traditional Practice	0.4970	0.4689	1.5972	1.0136	1.0000	0.5733
Human	0.6308	0.5645	1.0952	1.3880	1.7443	1.0000

Table 7 Normalized matrix and relative weight

	Organizational	Financial	Performance	Technological	Traditional Practice	Human	Relative weight
Organizational	0.2243	0.2238	0.2331	0.1772	0.2367	0.2415	0.2228
Financial	0.2861	0.2854	0.2904	0.3304	0.2509	0.2699	0.2855
Performance	0.1017	0.1038	0.1057	0.1302	0.0736	0.1391	0.1090
Technological	0.1348	0.0920	0.0864	0.1065	0.1160	0.1098	0.1076
Traditional Practice	0.1115	0.1338	0.1687	0.1079	0.1176	0.0873	0.1212
Human	0.1415	0.1611	0.1157	0.1478	0.2052	0.1524	0.1539

Table 86 weight of main and its associated sub barriers

Financial (0.2855)	**Human (0.1539)**	**Organizational (0.2228)**	**Performance (0.1090)**	**Technological (0.1076)**	**Traditional Practice (0.1212)**
Cost of applying lean tools (0.4308)	Lack of lean awareness (0.3536)	Lack of support from top management (0.3684)	Time and commercial pressure (0.4404)	Long implementation period (0.4022)	Influence of traditional management practices (0.3758)

Cost of lean training (0.3484)	Lack of lean specialist and expertise (0.3182)	Slow decision-making process (0.1963)	Uncertainty in the production process (0.2403)	Lack of knowledge of lean construction approaches (0.3500)	Lack of technological adaptations (0.2145)
Financial Crisis (0.2208)	Worker's attitude and resistance to change (0.1663)	Fragmentation and subcontracting (0.1771)	Lack of provision of benchmark performance (0.1860)	Use of non-standard components (0.1276)	Ineffective communication channels (0.2051)
	Multicultural workforce and language barrier (0.1619)	Unfavorable organizational culture (0.1340)	Lack of robust performance measurement system (0.1333)	Lack of support from the government (0.1202)	Difficulties in understanding concepts of lean (0.2046)
		Design/ Construction dichotomy (0.1242)			

Measurement of leanness rating score at third level

The evaluation of the barrier dimension at the third level is based on the leanness rating score by obtaining opinions of the stakeholders of the building construction sector. Therefore, as mentioned earlier, five comprehensive descriptions of leanness rating scales are prepared and discussed with experts. The leanness rating scales are defined by considering the impact and severity of barriers and its future implementation in the work. Thus, all experts completely agreed with the description of the leanness rating scale. The final derived leanness rating scales are presented in Table 9.

Table 9 Proposed description of the leanness rating scale

I	**Extensive**	These will act as extensive hurdles in implementing a lean concept in a whole construction site and there will be no chances for further modification in the future that by somehow lean concept can be implemented.
II	**Major**	These will act as major hurdles in implementing a lean concept in a whole construction site and there will be little or very few chances for further modification in the future that by somehow lean concept can be implemented.
III	**Moderate**	These will act as moderate hurdles in implementing a lean concept in a whole construction site whereas it will help in implementing a lean concept in some subpart of construction projects and there will be more chances of future implementation of lean in construction projects.
IV	**Some What**	These will act as somewhat hurdles in implementing a lean concept in a whole construction site as with the very few modifications in existing policies and human resources lean can be very easily implemented for performance enhancement.
V	**Not a Barrier**	These will act as not hurdles in implementing a lean concept, as the construction site is already in a condition that they can simply implement lean concept without modifications in the existing policies or human resources.

Similarly, the range of values for quantifying the sub barriers is also discussed with experts. Out of which major experts completely agreed to the range for sub barriers. However, remaining experts suggested minor changes to the range of values for some barriers; these changes suggested by experts are implemented into the final range of values for the sub barriers, which are described in Table 10.

Table 10 Range of values corresponding to sub barriers

Sr. No.	Main Barrier	Sub Barrier	Kindly tick (✔) on the most appropriate SCORE on the given scale for your project according to your views					
1	Financial Barriers	willing to bear Cost in applying lean tools	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not applied	<= 0.2 % of project cost	0.2 - 0.4 % of project cost	0.4 - 0.6 % of project cost	>= 0.6 % of project cost
2		Willing to bear Cost of lean training	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not applied	<= 0.2 % of project cost	0.2 - 0.4 % of project cost	0.4 - 0.6 % of project cost	>= 0.6 % of project cost
3		Financial Crisis	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very Constrained	Constrained	Not at all	Liberal	Very Liberal
4	Human Barriers	Lean awareness	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Less	Moderate	High	Expertise
5		Lean specialist and expertise	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Less	Moderate	High	Expertise
6		Worker's attitude and resistance to change	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Never	Rarely	Often	Mostly	Always
7		Multicultural workforce and language barrier	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Critical	High	Moderate	Less	Not at all
8	Organizational Barriers	Support from top management	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Less	Moderate	High	Very High
9		Decision-making process	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very slow	Slow	Moderate	Prompt	Very Prompt
10		Fragmentation and subcontracting	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	<= 5 % of project cost	5 - 10 % of project cost	10-20 % of project cost	>= 20 % of project cost
11		Organizational culture	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Unfavorable	Rarely favorable	Moderately favorable	Favorable	Very favorable
12		Design / Construction dichotomy	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very High	High	Moderate	Less	Not at all

13	Performance Barriers	Time and commercial pressure	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very High	High	Moderate	Less	Not at all
14		Uncertainty in the production process	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	>=40 %	30 - 40 %	20 - 30 %	10 - 20 %	<=10%
15		Provision of benchmark performance	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Verbal appreciation	Incentive appreciation	Recognized	Highly recognized
16		Robust performance measurement system	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Under Design	About to implement	Implemented	Highly implemented
17	Technological Barriers	Implementation period	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very delayed	Delayed	Moderate	Prompt	Very Prompt
18		Knowledge of lean construction approaches	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	Less	Moderate	High	Expertise
19		Use of non-standard components	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Always	Mostly	Often	Rarely	Never
20		Support/Grant from the government for technological advancement	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Not at all	<= 5 % of project cost	5 - 10 % of project cost	10-20 % of project cost	>= 20 % of project cost
21	Traditional Practice Barriers	Influence of traditional management practices	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very High	High	Moderate	Less	Not at all
22		New technological adaptations	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very less	Less	Moderate	High	Very High
23		Communication channels	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very ineffective	Ineffective	Normal	Effective	Very effective
24		Difficulties in understanding concepts of lean	**Scale →**	**1**	**2**	**3**	**4**	**5**
			Description →	Very hard	Hard	Normal	Easy	Very easy

Measurement of main barriers' index at the second level (using TOPSIS)

As mentioned previously, TOPSIS is used to computing index. Assume that the value of willing to bear the cost in applying lean tools, willing to bear Cost of lean training, and financial crisis are obtained 4, 4, and 2 respectively at the third level. Then as depicted in Table 11, the evaluation process is carried out using Microsoft Office Excel (2007), and the value of the financial barrier index (FBI) is obtained 0.6368. Similarly, the human barrier index (*HBI*), organizational barrier Index (*OBI*), performance barrier index (PBI), technological barrier index (TBI), and traditional practice barrier index (*TBPI*) can also be determined by computing their associated sub barriers.

Table 11 Evaluation of financial barrier index using TOPSIS

Sub barriers	Cost of applying lean tools	Cost of lean training	Financial Crisis		Si +	Positive Closeness Si +		
Weights	**0.4308**	**0.3484**	**0.2208**					
Score	4.0000	4.0000	2.0000		0.1481	0.0044	0.0029	0.0146
Excellent	5.0000	5.0000	5.0000		0.0000	0.0000	0.0000	0.0000
Critical	1.0000	1.0000	1.0000		0.3781	0.0707	0.0462	0.0260
r	6.4807	6.4807	5.4772					
Normalization rij					**Si -**	**Negative Closeness Si +**		
Score	0.6172	0.6172	0.3651		0.2596	0.0398	0.0260	0.0016
Excellent	0.7715	0.7715	0.9129		0.3781	0.0707	0.0462	0.0260
Critical	0.1543	0.1543	0.1826		0.0000	0.0000	0.0000	0.0000
Weighted Vij					**Financial Barrier Index (FBI)**			
Score	0.2659	0.2150	0.0806		FBI	0.6368		
Excellent	0.3324	0.2688	0.2016		Excellent	1.0000		
Critical	0.0665	0.0538	0.0403		Critical	0.0000		

Measurement of Leanness Index at first level (using WSM)

The final index of leanness can be evaluated using the formula (14):

LAI = ($W1$ × FBI) + ($W2$ × HBI) + ($W3$ × OBI) + ($W4$ × PBI) + ($W5$ × TBI) + ($W6$ × TPBI)

= ($W1$ × 0.2855) + ($W2$ × 0.1539) + ($W3$ × 0.2288) + ($W4$ × 0.1090) + ($W5$ × 0.1076) + ($W6$ × 0.1212)

The LAI is a score of main and its associated sub barriers. Its value varies from 0 to 1. However, these values are to compare building construction sites with regard to their leanness. This comparison can be obtained by placing the evaluated values in a ranking system. Table 12 suggests a ranking scale for this study. Thus, this approach proposes a value to show the construction site ranking method based on their leanness value.

The LI can help the owners to understand leanness about construction site. Owners can also implement lean tools and lean practices to improve leanness for future work or projects.

Table 12 Leanness rating scale

Leanness Category	LI Score
Extreme	0.80 – 1.00
High	0.60-0.80
Moderate	0.40 – 0.60
Low	0.20 – 0.40
Non Lean	0.00 – 0.20

Illustration and Validation of Proposed Index

To illustrate and validate the proposed methodology, a total of 5 construction sites of Surat city are evaluated. The leanness of these 5 sites was evaluated by applying this developed methodology. In this context, first collected the ratings of 24 sub barriers (at third level) for all the sites. These values are obtained by discussing with the architect/site engineers sites. Then, the LI of each site is obtained by evaluating the main barriers index (at the second level) (at first level). Thus, the obtained LI of each site is depicted in Table 13.

Table 13 Leanness score of various sites

Site	Leanness Score	Leanness Category	Rank
Site-1	0.4415	Moderate	4
Site-2	0.4628	Moderate	3
Site-3	0.5089	Moderate	2
Site-4	0.7151	High	1
Site-5	0.2489	Low	5

VIII. CONCLUSION

In the hierarchical structure, the LAI is at the top (first) level; barriers are at the second level and associated sub barriers are at the bottom (third) level. For assessment, the MCDM techniques WSM, TOPSIS, and AHP were used at various levels of the hierarchical structure. The relative weights at the second and third level were determined by the AHP. Out of all barriers, 'financial barrier' has the highest weight (0.2855). It means experts believe that for successful implementation of the lean building construction site should have good finance capabilities. In this connection, the concerned authority should have more attention to finance management of the construction sites. Similarly, time and commercial pressure, cost of applying lean tools, long implementation period, influence of traditional management practices, lack of support from top management, lack of lean awareness and cost of lean training obtained the highest weight (0.4404) (0.4308) (0.4022) (0.3758) (0.3684) (0.3536) (0.3484) respectively. This means that site owners should look after to overcome these issues first, for the successful implementation of lean. After that, five leanness-rating scales (I to V) were selected for the preparation of comprehensive descriptions: extensive, major, moderate, somewhat, and not a barrier. These rating scales are then correlated with the range of values for the quantification of sub barriers. For each sub barrier, a range of values has been given in qualitative terms (for the third level). These rating scales and range of values for sub barriers were assigned based on personal judgment and opinion from experts. Then, TOPSIS is used to determine the main barriers index at the second level. Finally, WSM is used to obtain LAI at the top level. The proposed application of LAI was then used to evaluate leanness for five construction sites of Surat. Thus, the LAI works based on the decision-making and basic judgment of the stakeholders of building construction site. This study is applicable to perform a comparison of construction sites in terms of leanness, and this can help the organization to make decisions and manage the assets that enhance the leanness of building construction.

The developed LAI can be revised by updating and revising relative weights of various factors and make more generalized to use in any region or country by following the same methodology of this study. Further study can be conducted to increase the leanness of the buildings. In fact, the developed LAI and its evaluation methodology will be useful to the assets managers of infrastructure. In brief, this study presents a novel approach to evaluate the leanness of building construction sites considering the impact of lean barriers using MCDMs.

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