



UTS
ePRESS

Construction
Economics and
Building

Vol. 21, No. 3
September 2021



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Citation: Aslam, M., Gao, Z., and Smith, G. 2021. Development of Lean Approaching Sustainability Tools (LAST) Matrix for Achieving Integrated Lean and Sustainable Construction. *Construction Economics and Building*, 21:3, 176–197. <http://dx.doi.org/10.5130/AJCEB.v21i3.7653>

ISSN 2204-9029 | Published by UTS ePRESS | <https://epress.lib.uts.edu.au/journals/index.php/AJCEB>

ARTICLE (PEER REVIEWED)

Development of Lean Approaching Sustainability Tools (LAST) Matrix for Achieving Integrated Lean and Sustainable Construction

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DOI: <http://dx.doi.org/10.5130/AJCEB.v21i3.7653>

Article History: Received: 29/03/2021; Revised: 12/06/2021 & 08/07/2021; Accepted: 12/07/2021; Published: 10/09/2021

Abstract

Challenges exist across the three dimensions of construction sustainability (economic; social and environmental) due to low productivity, waste, safety, and environmental hazards attributed to existing construction management practices. Lean construction (LC) has been widely accepted as a robust philosophy to enable sustainable construction (SC) practices. However, the existing literature is more inclined toward defining the integration between LC and sustainability through LC practices and techniques. Little research tackles the challenges of achieving sustainable goals within the current practices. Therefore, this paper aims to present a strategy that can help the construction industry overcome the challenges of SC in the traditional construction management practice by using LC. The challenges of SC are identified through a systematic literature review approach with metadata analysis. Compared with LC principles, tools and techniques, the strategy focused on identifying (1) the power and potential of LC principles and (2) the

DECLARATION OF CONFLICTING INTEREST The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. **FUNDING** The author(s) received no financial support for the research, authorship, and/or publication of this article.

best LC practices/techniques that help in overcoming these SC challenges. The study results showed 20 out of 32 challenges identified can be overcome by using LC integrated with SC. Finally, a Lean Approaching Sustainability Tools (LAST) matrix is developed to provide guidelines to the construction stakeholders for the selection of LC practices/tools/techniques in overcoming the top 15 most important challenges.

Keywords

Sustainable Construction; Lean Construction Tools and Techniques; Matrix; Sustainability Challenges; Integration

Introduction

The construction industry is prone to many wasteful practices; excessive use of energy and resources, generation of environmental hazards, and increased safety and health issues ([Othman and Nadim, 2010](#); [Serpell, Kort and Vera, 2013](#)). Considering the anticipated average growth rate of construction of 3.9% per year ([Robinson, 2019](#)), it is projected that the construction industry might suffer more from a severe shortage of natural materials and skilled manpower. The construction industry will bear the resulting higher costs and will be held more responsible for its impact on the environment and society in the future. The industry now has realized the importance of making the construction as sustainable as possible socially and environmentally, while the economy was still the key focus for the construction industry. The concept of sustainable development was introduced to the construction industry in the 1990s ([Kibert, 1994](#)). Early efforts were proposed to achieve sustainability within three domains described as environment, social, and economy. These three domains are known as the triple bottom line ([Nahmens and Ikuma, 2012](#); [Isa, Samad and Alias, 2014](#)). Accordingly, an abundance of research efforts since 1990 can be found on how to make construction as sustainable as possible. Programs such as Leadership in Energy and Environmental Design (LEEDS) in the USA, Building Research Establishment Environmental Assessment Methodology (BREEAM) in the UK, have helped the construction industry move toward sustainable construction (SC).

Despite all the benefits as well as the driving force from Government/State-initiated programs/certifications, the required boom in sustainable construction (SC) is lacking within the construction industry ([Tokbolat, et al., 2019](#); [Karji, Namian and Tafazzoli, 2020](#)). The researchers believe that existing construction management practices are still far from fully achieving the SC goals measured by the triple bottom line ([Tokbolat, et al., 2019](#); [Karji, Namian and Tafazzoli, 2020](#)). Unfortunately, many constraints within current project management practices hold the industry down for fully inculcating the SC practices. Some examples of the most common constraints are (1) a non-collaborative culture/silo working environment ([Robichaud and Anantatmula, 2011](#)), (2) late involvement of contractors ([Lam, et al., 2010](#)), (3) high initial cost ([Pham, Kim and Luu, 2020](#)), and (4) fear/uncertainty of adopting new or innovative methods ([Tafazzoli, Nochian and Karji, 2019](#)). The main problem causing these constraints is that most SC practices are implemented without aligning with construction management processes ([Sourani and Sohail, 2005](#)).

On the other hand, at the same time, the construction industry has also adopted another philosophy to improve the construction project management process, which is Lean construction (LC). LC has been approved as an effective practice for reducing construction materials and process wastes, while meeting the customer's requirements, adding value, and maintaining a continuous flow of processes in a very collaborative and people respective environment ([Howell, 1999](#); [Koskela, et al., 2002](#); [Abdelhamid, El-Gafy and Salem, 2008](#)). Due to the similarity of waste reduction in both LC and SC and realizing the need for the construction industry to implement SC, researchers started to explore the integration of SC practices with LC.

Over time, researchers explored the significance of using LC for implementing SC by exploring synergies, benefits, and trade-offs between them. Many studies have cited the positive impact of LC in

achieving SC goals ([Bae and Kim, 2008](#); [Johnsen and Drevland, 2016](#); [Khodeir and Othman, 2018](#)). The successful integration potentials between LC and SC can provide a way forward for overcoming the SC challenges using LC practices. However, the dilemma is that although most of the previous integration efforts of LC with SC have developed the context for using LC in achieving SC goals, its focus only remained at the theory level. However, the main questions such as why and how LC can help the construction industry in overcoming the existing SC challenges remain unanswered. There is a need for further exploration of the benefits of LC in overcoming the SC challenges commonly in the construction management processes. Addressing the challenges of SC through LC will take the integration effort from theory up to the implementation level.

Therefore, this study focuses on exploring the potential for LC to overcome SC challenges. LC principles, as well as tools and techniques, will be evaluated to determine their capabilities in overcoming the challenges of implementing SC practices. The outcome of this study provides a way forward to the construction industry for the implementation of SC within the LC environment. The specific objectives of this study are:

- Identify the common challenges being faced by the construction industry in achieving the SC goals within the existing management practices.
- Identify the potentials of LC in overcoming the challenges of SC.
- Developing a Lean Approaching Sustainability Tools (LAST) matrix for addressing the top SC challenges by LC practices (tools and techniques).

Methodology

The overall methodology of the study, as shown in [Figure 1](#), includes (1) systematic literature review (SLR), (2) metadata analysis, and (3) matrix establishment. The metadata analysis will identify the challenges for implementing SC by the construction industry. These challenges will be cross matched with LC principles and drivers for determining the capabilities of LC principles/drivers in overcoming these challenges. Using the available literature resources through SLR, the existing implementation status of LC will be assessed to identify the common challenges between LC and SC. Then LC practices/tools/techniques will be evaluated to determine their likelihood of overcoming SC implementation challenges. The objectives and functionalities of practices (including tools and techniques) will be used to assess those LC practices that have the potential of triggering the respective SC challenges. In the end, a LAST matrix showing the LC practices/tools/techniques that can be effective in overcoming the SC challenges will be developed.

A SLR process was carried out based on the guidelines provided by [Liberati, et al. \(2009\)](#) and [Mok, Shen and Yang \(2015\)](#). To improve the quality of research, literature studies were extracted from the existing body of knowledge using three stages as shown in [Figure 2](#). Different criteria were established at each of the three stages to retain the quality papers for analysis as described below.

In Stage 1, published literature (journal papers, conference papers, industrial reports, academic papers) from sources that have a peer-reviewed process of evaluating the papers such as Elsevier, Taylor and Francis series web, American Association of Civil Engineers (ASCE), Multidisciplinary Digital Publishing Institute (MDPI), Springer, International Group for Lean Construction (IGLC) and Emerald were identified. Google scholar was used to extract industrial reports and scholarly articles that meet the specific requirement of this study. The main approach for identifying potential papers was based on keywords formulated in four broader search groups: (1) LC principles/drivers, (2) LC practices/tools/techniques, (3) Integration of LC and SC, and (4) Challenges of SC. In summary, 195 papers/reports in total were identified in the initial search. Some examples of keywords/sentences used for literature search are 1) LC implementation process, LC implementation methods, LC implementation tools, LC implementation

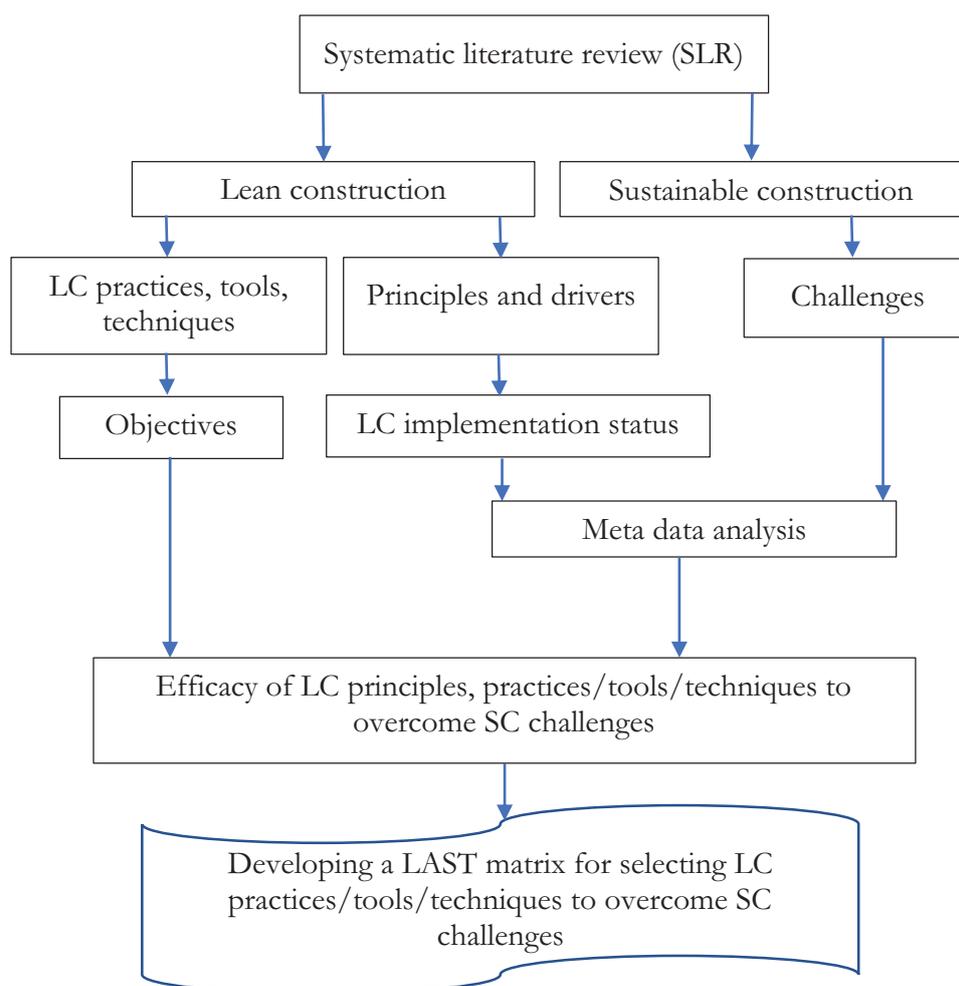


Figure 1. Overall research methodology

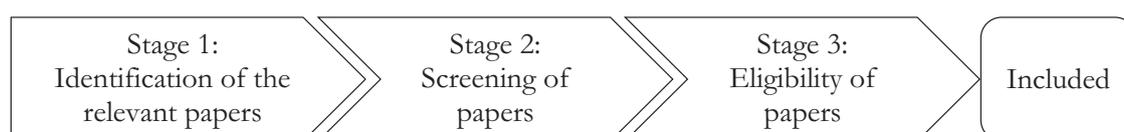


Figure 2. Stages of Systematic Literature Review (SLR) process

techniques; 2) present status of LC adoption and implementation, present progress of LC adoption and implementation, present rate of LC adoption and implementation; 3) SC challenges, SC barriers, SC shortcomings, SC problems; 4) objectives of LC methods, objectives of tools and technique; 5) LC principles, LC drivers, LC enablers, LC facilitators, LC critical success factors; 6) Integration of LC with SC, and 7) Compatibility of LC with SC.

In Stage 2, the 195 papers were screened based on their years of publication and for potential duplicate content. Considering the theoretical and practical evaluation of LC and SC, it was decided to keep the initial conceptual papers that pioneered both these concepts, but not earlier works that may have contained materials used in the development of the concepts. Key development periods were also used in screening. For SC, the late 1980s, when the Brundtland report was published was chosen as the starting point. For the

LC early 1990s, when LC started to evolve, was selected as the starting point. After Stage 2 screening, 119 papers/reports were retained for further consideration.

In Stage 3, the abstracts of the papers were read to verify the relevancy of the identified papers with this study. When the scope of the paper matched the objectives of this study, a full paper review was carried out. As a result of the SLR analysis after this stage, a total of 74 papers were included in the final analysis.

Current Challenges of Adopting SC

PROGRESS TOWARDS SUSTAINABILITY

Evidence of waste and related environmental issues can be found in a variety of reports. According to [US EPA \(2016\)](#), the construction industry is responsible for the generation of around 548 million tons of waste in 2015 that contributed to pollution and other environmental hazards. Similarly, according to [Force's report \(1998\)](#), almost 10% of the construction material is wasted on most construction projects. [Pérez-Lombard, Ortiz and Pout \(2008\)](#) reported that the building sector was responsible for between 20% to 40% of energy consumption in developed countries which exceeds other sectors including industrial and transportation. Similarly, [Serpell, Kort and Vera \(2013\)](#), after consulting several studies, reported that the construction industry consumes 40% of raw materials and 25% of timber supplies along with 16% of water supplies. Furthermore, they report that construction generates around 40% of waste and produces 35-40% of carbon dioxide emissions. According to [IEA and UN \(2019\)](#) report, the final energy demand in buildings in 2018 increased by 1% from 2017, and 7% from 2010. Similarly, according to [Conti, et al. \(2016\)](#), International Energy Outlook 2016 with projections to 2040, if the energy demand of the building sector keeps on growing at the existing rate of 1.4%/year, there are likely chances that the energy consumption will be more than 48% higher in the year 2040 compared to 2012.

Despite the abundance of benefits of the SC, the adoption rate for SC practices in the construction industry is not very high ([Gunatilake, 2013](#)). Comparing the literature of early 2000 with the latest years, the generation of waste and consumption of energy continues to grow with the increasing demand for buildings and infrastructure. This suggests that the construction industry, from design through construction, has not fully adopted and implemented the SC practice in its true spirit ([Tokbolat, et al., 2019](#); [Karji, Namian and Tafazzoli, 2020](#)). Thus, there is a need for developing a strategy to overcome the challenges and barriers to implementing SC.

CHALLENGES IN ADOPTING SC

The available literature was extensively examined to identify the challenges impacting the implementation of SC in the context of construction management methods/processes. The list of challenges and categories of those challenges are all detailed out in [Table 1](#). The total number of citations is used as a ranking method of challenges in the study.

Among these 32 challenges, the top 15 challenges with respect to their number of citation (≥ 5) as shown in [Table 1](#) along with some of the key source references are as follows:

1. High initial and operating cost for incorporating the sustainability practices ([Hwang, Shan, and Lye, 2018](#); [Tokbolat, et al., 2019](#))
2. Regulatory barriers towards adopting innovative techniques for SC ([Yates, 2014](#); [Ogunsanya, et al., 2019](#))
3. Lack of knowledge/awareness of how SC can be applied in construction ([Lam, et al., 2010](#); [Chan, et al., 2017](#); [Opoku, Ayarkwa and Agyekum, 2019](#))

Table 1. Challenges in implementing SC

S/No	Challenges in implementing SC	Number of Citations	Ranking
Category 1: Organizational/cultural (12 challenges)			
1.	Lack of commitment/consideration	13	4*
2.	Resistance to change	10	6*
3.	Fear/uncertainty for implementing new and innovative changes	10	6*
4.	Lack of incentives	8	7*
5.	Less focus on environment and social aspects	7	8*
6.	No inbuilt culture for sustainability	4	11
7.	No consideration for Life cycle cost analysis	5	10*
8.	No consideration for measuring Sustainability	4	11
9.	Constructability issues	4	11
10.	No in-Built quality	3	12
11.	Non- involvement of external stakeholders	2	13
12.	Dependence on other sectors	2	13
Total		72	
Category 2: Contractual and Relational (5 challenges)			
13.	Non-involvement of the contractor at early stages	6	9*
14.	Silo working	6	9*
15.	Responsibilities for SC are not defined	3	12
16.	Fear of change orders	2	13
17.	Less time for selection contractor	1	14
Total		18	
Category 3: Government (2 challenges)			
18.	No regulations for sustainability compliance	15	2*
19.	Lack of interest from Govt agencies	11	5*
Total		26	
Category 4: Knowledge and awareness (3 challenges)			
20.	Lack of knowledge for SC and how to apply/manage SC in construction	14	3*
21.	Lack of awareness	4	11
22.	Lack of training opportunities	3	12
Total		22	

Table 1. continued

S/No	Challenges in implementing SC	Number of Citations	Ranking
Category 5: Construction and Management (10 challenges)			
23.	High initial cost	21	1*
24.	Not well-defined processes for managing wastes	7	8*
25.	Lack of use of technology	6	9*
26.	Unsustainable project management practices	4	11
27.	Lower supply of green materials and components	5	10*
28.	Poor communication among different parties	3	12
29.	Focus on activity management and not on the end product	3	12
30.	Fragmentation	3	12
31.	Unconfined environment	1	14
32.	Adverse working conditions	1	14
Total		52	

Notes: within the list of top challenges – Number*- for example, 1*

4. Lack of commitment/consideration for SC from owners and top management ([Häkkinen and Belloni, 2011](#); [Tafazzoli, Nochian and Karji, 2019](#))
5. Lack of support/strict rules from the Government departments for implementing SC
6. Fear/uncertainty of adopting new or innovative methods for management ([Yates, 2014](#); [Ogunsanya, et al., 2019](#))
7. The general attitude of the construction industry resists any changes (cultural or management) within its existing practices ([Durdyev, et al., 2018](#); [Olawumi and Chan, 2020](#))
8. Inadequate incentives for private sectors by the owners/top management and govt or lack of end-user demand ([Chan, et al., 2017](#))
9. More focus on cost and schedule than on environment and social aspects ([Baloi, 2003](#); [Robichaud and Anantamula 2011](#))
10. Lack of guidance for managing the material wastes and process ([Chang, et al., 2016](#); [O'Connor, Torres and Woo, 2016](#))
11. Process of selecting the contractors based on the lowest cost ([Lam, et al., 2010](#))
12. Individuality approach/silo thinking between designers, contractors, and subcontractors ([Häkkinen and Belloni, 2011](#); [Hwang, Shan, and Lye, 2018](#))
13. Lack of use of technology ([Opoku, Ayarkwa and Agyekum, 2019](#); [Olawumi and Chan, 2020](#))
14. More focus on gaining rapid profits without any consideration to life cycle cost analysis of the projects ([Robichaud and Anantamula, 2011](#); [Bon and Hutchinson, 2000](#))
15. Lower supply of green material ([Bon and Hutchinson, 2000](#); [Ogunsanya, et al., 2019](#))

Integration of LC and SC

Inspired by Lean manufacturing, LC was evolved as a philosophy to reduce waste within construction materials and processes, adding value to the customer's need, and maintaining continuous flow in a

collaborative and people respective environment. According to the theoretical assessment of the previous research efforts, LC and SC have the potentials to integrate with each other. This inference is based on many common goals already identified between LC and SC like (1) Reduction of waste ([Johnsen and Drevland, 2016](#)), (2) improvement of health and safety conditions ([De Carvalho, et al., 2017](#)), (3) increased process efficiency and productivity ([Carvajal-Arango, et al., 2019](#)), (4) continuous improvement ([Francis and Thomas, 2020](#)), (5) costs reduction ([Belayutham, González and Yiu, 2017](#)), and (6) increased quality, process efficiency and productivity ([De Carvalho, et al., 2017](#)). The previous research is quite successful in reaching a point that can convince the construction industry in using the LC for effectively implementing SC practices. The integration motivated the new study of using LC to overcome SC challenges.

LEAN CONSTRUCTION PRACTICES

To facilitate LC implementation, most of the studies evaluated the impact of lean tools, techniques, systems, theories, and methods (as listed in [Table 2](#)), which have been consistently used to achieve the principles of LC. As an example, to ensure root cause analysis and continuous improvements as objectives of LC, techniques like Six Sigma (SS) ([Beary and Abdelhamid, 2005](#)), failure mode effect analysis (FMEA) ([Sawhney, et al., 2010](#)), and Fail-safe for quality and safety (FSQS) ([Salem, et al., 2005](#)) have been used by many researchers. Similarly, to optimize production system/schedules, focusing the customers value, improving workflow, and reducing variabilities as key principles of LC, methods like Just in time delivery (JIT), Value stream mapping (VSM), and prefabrication/modular ([Singh and Kumar, 2020](#)) have been recommended. Some researchers have strongly recommended theories like the Theory of constraints (TOC) ([Issa, 2013](#)) and Total quality management (TQM) ([Ansah and Sorooshian, 2017](#)) for constraint analysis and improving the quality as per the principles of LC, respectively. Several kinds of literature are available which assessed the efficacy of building information modelling (BIM) in implementing the LC principles ([Singh and Kumar, 2020](#)). Kanban (KAN) is used as a tool to facilitate the implementation of Pull production (PULL) ([González, Framinan and Ruiz-Usano, 2013](#)). Similarly, the Last planner system (LPS) has been developed as a complete system to implement LC with integral tools like master scheduling, phase scheduling with PULL concepts, look-ahead planning, weekly planning, measuring Percent plan completion (PPC) in a people-focused environment ([Ballard and Howell, 2003](#)). Tools like A3, displaying planning, safety, and progress charts/boards along with the use of informational technologies for rapid sharing of information are effectively embedded into the concepts of visual management. Other tools/techniques like Big room (BR), Performance-based contracting (PBC), Poka yoka (PY), 5S, and Concurrent engineering (CE) ([Ansah and Sorooshian, 2017](#); [Singh and Kumar, 2020](#)) will further facilitate the implementation process of LC.

Considering a large diversity in identifying the modalities of implementing LC like tools, techniques, methods, theories, and concepts, this research combined these different modalities under the common name of LC facilitators. These facilitators have been comprehensively analysed by [Aslam, Gao and Smith \(2020\)](#) based on their objectives and functions, as shown in [Table 2](#).

Where the theories of SC fell short in explaining the modalities of how to achieve SC goals within the construction environment ([Sarhan, et al., 2018](#)), those LC practices in [Table 2](#) provide a perfect platform for integrating practices to achieve sustainability in construction. Many researchers explored LC practices for their impact on construction sustainability and reported positive relationships or the potential for positive impact ([Nahmens and Ikuma, 2012](#); [Ahuja, 2013](#); [Francis and Thomas, 2020](#)). However, LC is still an emerging construction process and has not yet been fully adopted by the entire construction industry. The current implementation status of LC has to be considered as a controlling influence on LC efficacy in overcoming the SC challenges.

Table 2. Commonly used LC practices ([Aslam, Gao and Smith, 2020](#))

S/N	LC facilitators	Objective
1.	Last Planner System (LPS)	Reduce planning variabilities, improves the workflow, reduce process variabilities, continues improvement, improve visualization, customer focus, improve communication, pull approach
2.	Visual Management (VM)	Improve communication and visualization, continues improvement
3.	Daily Huddle Meetings (DHM)	Involve the employees, improving working procedures, reduce process variabilities
4.	First Run Studies (FRS)	Continues improvement, improve the working procedure, reduce, better visualization, improve workflow
5.	5S	Reduce process variabilities, improve working procedures, maintain material flow, safety
6.	Fail-Safe for Quality and Safety (FSQS)	Defect control, reduce process variabilities, improve quality and safety
7.	Six Sigma (SS)	Process and production variability reduction, control defect rates, customer focus, continues improvement
8.	Kanban (KAN)	Systematic management of the demands, reduce process variabilities, improve material flow, safety control
9.	Just in Time (JIT)	Reduce planning and process variabilities, improve workflow, improve material Flow
10.	Kaizen (KAIZ)/Continues improvement	Continues improvement, reduce process variabilities, control defects, improve workflow
11.	Concurrent Engineering (CE)/Integrated design	Customer focus, reduce design variabilities, improve workflow
12.	Prefabrication/Modular (PREFAB/MOD)	Reduce planning, design, and process variability, improve workflow, improve working procedures
13.	Line of Balance (LOB)	Minimize interruption between workflows, reduce process variabilities, maintain the material flow
14.	Poka Yoka (PY)	Reduce variabilities in construction processes due to mistakes, improve workflow
15.	Theory of Constraints (TOC)	Improve the rate of flow by reducing the constraints, reduce planning, design and process variabilities, maintain material flow, safety
16.	Standardized Processes (SP)	Continues improvement, reduce process variabilities, Improve workflow
17.	Building Information Modelling (BIM)	Better visualization, reduce planning, design and process variabilities, customer focus, improve communication

Table 2. continued

S/N	LC facilitators	Objective
18	Integrated Project Delivery (IPD)	Reduce planning, design, and process variabilities, improve flow, improve communication
19	Set-Based Design (SBD)	Reduce design variabilities, improve workflow
20	Target Value Design (TVD)	Reduce planning and design variabilities, customer focus
21	Value Stream Mapping (VSM)	Better visualization, reduce process variabilities, maintain continuous flow of information and material, better visualization, customer focus
22	Failure mode effect Analysis (FMEA)	Defect analysis and control, reduce planning and process variabilities
23	Collaboration using Big Room (BR)	Reduce planning variabilities, improve workflow, reduce process variabilities, continues improvement, improve visualization, customer focus, improve communication
24	Total Quality Management (TQM)	Remove quality issues very first time, built-in quality, reduce planning and process variabilities
25	Performance-based contracting (PBC)	Reduce planning, design, and process variabilities, improve workflow
26	Pull approach (PULL)	Process and production variability reduction, improve workflow, systematic management of the demands, reduce the work in process

IMPACT OF LC PRINCIPLES/DRIVERS IN REMOVING THE SHORTCOMINGS WITHIN SC

To consider the integration of LC and SC it would be of great value to the construction industry if the efficacy of LC principles and practices in overcoming the prevalent SC implementation challenges are assessed. LC principles and drivers are different concepts, and many kinds of literature either only explained principles or only identified drivers; however, comparing the SC challenges only with LC principles will not reflect the true capabilities of LC in overcoming the SC challenges. This is because the list of LC principles is very brief, and they don't cover all the dimensions of LC. Therefore, drivers of LC are further augmented with LC principles to cover most of the LC aspects. The challenges as outlined in [Table 1](#) have to be minimized to efficiently implement SC. The development of LC principles and drivers can provide a way forward to the lean practitioners for implementing LC in its true spirit. LC principles and drivers are established to further facilitate the achievement of the main goals of LC that are waste reduction, adding value, and maintaining a continuous flow. The theories, tools, and philosophies of LC are influenced and adapted from the Lean Production System (LPS) inspired by Toyota motors. Similarly, the principles of LC are also derived from the LPS ([Womack and Jones 1996](#); [Liker 2004](#)). Extensive work has already been carried out in developing the comprehensive principles of LC by [Diekmann, et al. \(2004\)](#), [Koskela \(1992, 2000\)](#), [Sacks, et al. \(2010\)](#) and [Khodeir and Othman \(2018\)](#). As a result, 35 major principles and drivers of LC are identified. The principles of LC and their capabilities in achieving the goals of SC were cross matched with the prevalent challenges of implementing SC as shown in [Table 3](#). Based on the frequency of LC principles/drivers in overcoming the SC challenges, ten (10) most influential principles/

drivers in overcoming most of the SC challenges are 1) people involvement, 2) collaboration, 3) integrated design and delivery system, 4) increased output value through systematic consideration of customer requirements 5) target value and cost among other alternatives, 6) JIT delivery, 7) optimize work content, production schedules, and production system, 8) use visual management, 9) benchmark, and 10) continuous improvement.

Theoretically, if a particular area of LC is struggling to overcome implementation challenges, there is a high likelihood that it will be equally difficult for that particular area of LC to facilitate SC in overcoming a similar challenge. For example, the lack of commitment from top management is the most common implementation challenge of LC. If a group of LC tools and techniques have difficulty in overcoming this challenge, those tools and techniques would not likely be successful in overcoming a similar challenge in SC. Some of the common challenges between LC and SC identified in the SLR were (1) the lack of commitment/consideration ([Kawish, 2017](#)), (2) resistance to change ([Sarhan and Fox, 2013](#)), (3) fear/uncertainty for implementing new and innovative changes ([Warcup, 2015](#)), (4) lack of awareness ([Simonsen, Thyssen and Sander, 2014](#)), and (5) the lack of interest from government agencies ([Sarhan and Fox, 2013](#)). Other challenges for implementing LC were adopted from the study conducted by [Gao, Aslam and Smith \(2020\)](#), as shown in the column of Status of LC implementation in [Table 3](#). The LC principle or driver is rated as either “*Struggling*” or “*Helpful*” in overcoming the challenge to SC. “*Struggling*”, in the Status of LC column, is where LC is not currently successful in overcoming the challenge similar or the same as what is shown for SC. “*Helpful*” indicates that the LC principle/driver shown is considered helpful in resolving the SC challenge.

[Table 3](#) shows that LC is thought to be helpful with 20 of the 32 SC challenges based on current LC implementation. LC helps overcome the 7 challenges of SC whereas it struggles in overcoming 5 challenges within the category of organization/culture. Similarly, LC also struggles in overcoming the challenges related to Government support, knowledge, and awareness. LC itself needs substantial uplift in the categories of government support and knowledge/awareness. Effective awareness and educational programs from Government can substantially improve the uptake of LC which in turn helps to achieve the SC, because LC has the principles/drivers that can help in overcoming the challenges related to these two categories. The present implementation of LC indicates the efficacy of LC in overcoming the challenges of SC related to categories of contract/relationships and construction/management. Even with the present implementation/knowledge status of LC, the construction industry can substantially improve its sustainability goals, especially by overcoming the challenges related to contract/relationship and construction/management.

In summary, it can be seen that where the theory of LC has the principles/drivers that can help in achieving the SC by overcoming SC challenges, the implementation status of some of the LC principles/drivers needs to be improved to fully achieve all the SC domains.

It has to be mentioned that many principles and drivers have appeared multiple times in [table 3](#). This is because many LC principles and drivers can be useful in overcoming more than one specific challenge. As an example, the challenge like less focus on environment and social aspects can be overcome by using the LC principles/drivers of 1) Target value and cost among other alternatives, 2) Collaboration, 3) Increase output value through systematic consideration of customer requirements, and 4) People involvement. During target costing the aspects of environment and society can be discussed in a collaborative session duly represented by all stakeholders while highlighting its importance to the customers for further inclusion within the goals of the project. Similarly, the driver collaboration can also be useful in overcoming other challenges like the non-involvement of contractors at an early stage, no inbuilt culture for SC, no consideration for life cycle costing and so many others.

Table 3. Status of LC principles in overcoming the SC challenges

S/No	LC principles/drivers that can help	Status of LC	Challenges - SC
Category 1: Organizational/cultural (12 challenges)			
1.	Organizational commitment, empower the employees, long term partnership	Struggling	Lack of commitment/ consideration
2.	Increase transparency, use visual management, collaboration, target value and cost among other alternatives, benchmark, people involvement	Struggling	Resistance to change
3.	Increase transparency, use visual management, Collaboration, target value and cost among other alternatives, benchmark, people involvement, use of latest and trusted technologies	Struggling	Fear/uncertainty for implementing new and innovative changes
4.	Integrated design and delivery system	Helpful	Lack of incentives
5.	Target value and cost among other alternatives, collaboration, increase output value through systematic consideration of customer requirements, people involvement	Helpful	Less focus on environment and social aspects
6.	Promote a cultural change among the organization, people involvement, increase output value through systematic consideration of customer requirements, collaboration	Struggling	No inbuilt culture for sustainability
7.	Increase output value through systematic consideration of customer requirements, target value and cost among other alternatives, collaboration, people involvement, organizational learning	Helpful	No consideration for Life cycle cost analysis
8.	Benchmark, people involvement, continuous improvement	Helpful	No consideration for measuring sustainability
9.	Reducing the share of non-value adding activities, rectify the faults when originates at first	Helpful	Constructability issues
10.	Integrated project delivery system, development of multiskilled and cross-functional teams	Helpful	No in-built quality
11.	People involvement, Plan for the projects at the start and every time the activities are near to start	Helpful	Non- involvement of external stakeholders
12.	Collaboration, development of multiskilled and cross-functional teams, Integrated design and delivery system, long term partnership	Struggling	Dependence on other sectors

Table 3. continued

S/No	LC principles/drivers that can help	Status of LC	Challenges - SC
Category 2: Contractual and Relational (5 challenges)			
13.	Integrated design and delivery system, collaboration	Helpful	Non-involvement of the contractor at early stages
14.	Integrated design and delivery system, collaboration	Helpful	Silo working
15.	Collaboration, increase output value through systematic consideration of customer requirement, people involvement, empower the employees	Helpful	Responsibilities for SC are not defined
16.	Integrated design and delivery system, collaboration, increase output value through systematic consideration of customer requirement, people involvement, ensure requirement flow down	Helpful	Fear of change orders
17.	Integrated design and delivery system	Helpful	Less time for selection contractor
Category 3: Government (2 challenges)			
18.	Involvement of Govt to ensure LC	Struggling	No strict rules for sustainability appliance
19.	Continues improvement, benchmarking, involvement of Govt to ensure LC	Struggling	Lack of interest from Govt agencies
Category 4: Knowledge and awareness (3 challenges)			
20.	Optimize work content, optimize production system, optimize production schedules, simplify the whole process, collaboration, people involvement, integrated project delivery method	Struggling	Lack of knowledge for SC and how to apply/manage SC in construction
21.	Increase awareness for LC	Struggling	Lack of awareness
22.	Organizational learning	Struggling	Lack of training opportunities
Category 5: Construction and Management (10 challenges)			
23.	Reducing the share of non-value adding activities, reducing cycle times, reduce variability, increase output value through systematic consideration of customer requirements, ensure requirement flow down, continuous improvement, people involvement, JIT delivery, optimize work content,	Helpful	High initial cost

Table 3. continued

S/No	LC principles/drivers that can help	Status of LC	Challenges - SC
	optimize production system, optimize production schedules, simplify the whole process, collaboration, use of preassembly, prefabrication and modular construction, target value and cost among other alternatives, Apply to Pull approach, empower the employees		
24.	JIT delivery, Apply to Pull approach, reducing the share of non-value adding activities, increase output value through systematic consideration of customer requirements, use visual management, people involvement, standardization, use of preassembly, prefabrication, and modular construction	Helpful	Not well-defined processes for managing wastes
25.	Use of latest and trusted technologies	Helpful	Lack of use of technology
26.	Covers all principles of LC	Helpful	Unsustainable project management practices
27.	JIT delivery, increase output value through systematic consideration of customer requirements, people involvement, standardization, use of preassembly, prefabrication and modular construction, target value and cost among other alternatives	Struggling	Lower supply of green materials and components
28.	Meetings/planning at the start and every time the activities are near to start, people involvement, integrated design, and delivery system, collaboration	Helpful	Poor communication among different parties
29.	Optimize work content, optimize production system, optimize production schedules	Helpful	Focus on activity management and not on the end product
30.	No principles/driver available	Struggling	Fragmentation
31.	Optimize work content, optimize production system, optimize production schedules, reduce variability, reduce the share of non-value adding activities, increase flexibility, use visual management, JIT delivery, People involvement, collaboration	Helpful	Unconfined environment
32.	Optimize work content, optimize production system, optimize production schedules, reduce variability, reduce the share of non-value adding activities, increase flexibility, use visual management, JIT delivery, people involvement, collaboration	Helpful	Adverse working conditions

Developing Lean Approaching Sustainability Tools (LAST) Matrix for Evaluating LC Practices in Overcoming SC Challenges

EFFICACY OF LC PRACTICES (TOOLS AND TECHNIQUES) IN OVERCOMING SC CHALLENGES

Based on the theoretical concepts, the efficacy of LC tools and techniques were further examined in overcoming the challenges faced by the construction industry in implementing SC. The objectives of LC are used to evaluate the ability of LC tools and techniques to effectively overcome SC challenges. LC tools and techniques that can have a significant impact in overcoming those 32 challenges have been identified, but only the top fifteen (15) challenges are used to develop into a LAST matrix, as shown in [Table 4](#), based on their significance in literature citations discussed above.

LAST matrix shows that more LC tools and techniques are available to address some challenges like 1) high initial cost, 2) resistance to change, and 3) lack of guidance for material wastes and process optimization. As a comparison, only a limited number of tools/techniques are available to address some other challenges like 1) the lack of use of technology, 2) fear/uncertainty, and 3) lack of provision of incentives, and 4) silo working. The LAST matrix also shows that no LC tools and techniques are available to address the two challenges of 1) lack of interest from Government and 2) non-availability of strict rules/regulations for SC.

Further evaluation of the individual LC practices revealed that some LC tools and techniques like BIM, LPS, and BR (from [Table 3](#)) can help to comparatively eradicate a greater number of challenges (7 and 6 respectively out of 15 major challenges). Some other LC tools and techniques like DHM, KAN, PULL, LOB, and FMEA can only address one challenge each. Additionally, LC tools and techniques like FSQS and PY ([Table 3](#)) are not found to be significant in overcoming any of the major challenges; however, these tools can play some role in overcoming other challenges (apart from the 15 top challenges). Since the LAST matrix is developed for overcoming the top 15 challenges, the detailed analysis on overall 32 challenges revealed that these LC tools and techniques can also play a vital role in addressing other SC challenges like optimizing the project activities, unconfined environment-open area exposed to the public, constructability issues and adverse working conditions.

APPLICATION OF THE LAST MATRIX

The LAST matrix provides the guideline to the construction stakeholders for evaluating different LC practices in overcoming the respective major SC challenges. When choosing an LC tool or technique, it should be kept in mind that some LC tools and techniques are general, while others can be specific to the challenges. For example, BR is a tool to ensure collaboration and people involvement and can be effective in overcoming most of the challenges within all the categories. The challenges of 1) lack of commitment, 2) resistance to change, 3) no consideration for life cycle cost, 4) non-involvement of contractor, 5) silo working, and 6) high initial cost can be easily addressed through collaborative sessions duly represented by all the stakeholders in a BR platform. JIT is a specific tool that ensures effective material waste management and can only be effective in overcoming some of the shortcomings related to the category of construction and management to reduce material, process waste, and optimize the availability of green materials. Similarly, the tools like FRS, PBC, IPD, TVD, TOC, and CE are effective against very unique challenges for 1) removing the complexities, 2) selecting and involving the best contractor early, 3) integrated delivery of the project, 4) making the customers realize the sustainable environment and social goals, 5) removing the uncertainties and fear, and 6) integrating the sustainability aspects into the design and contracts, respectively.

Table 4. The LAST matrix

Major Challenges as Determined from Table 2	Lean Facilitators																										
	TQM	KAIZ	BR	SS	LPS	VM	TVD/SBD	BIM	IPD	VSM	DHM	CE	PBC	Prefab/Mod	5S	JIT	KAN	PULL	FRS	SP	FMEA	FSQS	PY	LOB	TOC	Total	
Organizational/cultural																											
Lack of commitment/consideration	X	X	X	X	X																						5
Resistance to change	X	X	X	X		X	X	X											X	X							9
Fear/uncertainty for implementing new and innovative changes								X											X						X		3
Lack of incentives									X																		1
Less focus on environment and social aspects					X		X	X		X	X																5
No consideration for Life cycle cost analysis			X		X		X	X		X																	5
Contractual and Relational																											
Non-involvement of contractor at early stages/lowest bidders			X						X			X	X							X							5
Silo working			X						X			X															3
Government																											
Lack of interest/legal specifications from Govt agencies																											0
No strict rules for sustainability appliance																											0
Knowledge and awareness																											
Lack of knowledge/awareness for SC and how to apply/manage SC in construction					X		X					X							X								4
Construction and Management																											
High initial cost		X	X		X		X	X	X	X				X	X	X			X		X				X	X	14
Lack of guidance for material wastes and process optimization					X	X				X				X	X	X	X	X									8
Lack of use of technology								X											X				X				3
Lower supply of green materials and components							X		X				X	X	X												5
Total	2	3	6	2	6	2	5	7	5	4	1	2	2	3	3	3	1	1	5	2	1	0	1	1	2		

To overcome the challenge of lack of commitment/consideration, the tools like KAIZ, TQM, LPS, BR, and SS are recommended in the LAST matrix. The tools like KAIZ, TQM, and SS will help in evaluating the benefits or improvements of using LC for achieving SC goals by ensuring the best quality delivered at the very first time without any defects. Realizing the initial benefits, the trust of top management for an integrated LC/SC approach will be increased thereby motivating increasing commitment for integrating SC.

LPS and BR can be applied to increase the commitment of the field management, suppliers, subcontractors, and workers by involving them during all the planning stages and making them realize the importance of SC. The challenges of fear/uncertainty, resistance to change, high initial cost, late selection of contractors, and lack of technology use can best be overcome using BIM as it improves the visualization and communication between different stakeholders. Early visualization of the end product, likely safety issues to be encountered, environmental effects, and construction processes will help the construction stakeholders understand and modify the complexities and working methodologies.

To improve the focus on environmental and social aspects, tools like BR, VSM, TVD/SBD, DHM, and LPS will be helpful to convince the stakeholders of the importance of sustainability. All these tools promote collaboration and involvement of people to identify non-value-adding activities along with other constraints adversely impacting the environment and society. Similarly, 12 tools are recommended to address high initial costs for sustainable events, among which JIT (delivering material at the right time and place to reduce material wastes), LPS (making the work-ready by removing constraints by involving last planners), BR/TVD/SBD (working in a collaborative environment to select the plans that are most cost-effective within the sustainability goals), and VSM (for identifying the wasteful practices within the construction processes) are the most prominent tools.

To address the challenges of Silo thinking/working approach, lack of incentives and late selection of contractors, IPD coupled with CE provides a complete system in which all the major stakeholders, like owners, consultants, and contractors, have a multi-party contract to share financial risks and rewards by applying a profit/incentive pool based upon measurable project outcomes. The collaboration between stakeholders will help in structuring the modalities for the profit and incentive pool to ensure that each member is accountable for its contribution to the project outcome.

Selection of the competent contractor having adequate sustainability awareness can be aided through using PBC by evaluating the capability of the contractor in meeting the sustainability goals. Knowledge for sustainability can be substantially improved through FRS. The complex processes can be given the first run to acquaint the whole team with how the processes can best be done. It would be more manageable to ensure the required demand for green material through Prefab/MOD construction. The prefabricated materials can be designed based on the availability of green materials and then can be better controlled under controlled and sustainable environments. By using the tools like BIM and KAIZ, the standard legal specifications can be better tailored based on the best site requirements as experienced by the construction stakeholders.

In summary, the LAST matrix can be used as a resource for identifying the LC practices to address the SC challenges. Although many LC practices have been recommended to overcome the challenges of the SC, the construction companies must evaluate each of them based on their organizational policy, project needs, available assets and resources, suppliers/subcontractor's capabilities, and in consensus with the project teams.

Conclusions and Recommendations

Based on the synergy between LC and SC and the efficacy of LC practices in triggering the SC goals, the potential of LC to overcome the prevalent challenges for implementing the SC was evaluated in this study.

Overall, 32 SC challenges were identified and placed into five categories. Based on the number of citations in the existing literature, it was found out that the challenges related to the categories of organization/culture and construction/management were most commonly evaluated and were considered as a higher priority to be addressed as compared to categories like contractual/relational, Government, and knowledge/awareness. The category of knowledge/awareness is comparatively more challenging for implementing SC as compared to contractual/relational and knowledge/awareness.

The analysis and the developed LAST matrix proved that LC tools and techniques have the capability of addressing SC Challenges. Thus, there is strong potential and applications for an integrated lean and sustainable construction. To select appropriate LC practices in the LAST matrix, objectives, and functionalities of LC tools and techniques were cross matched with the SC challenges to provide a guideline to the stakeholders in selecting the right tool for overcoming the respective challenges. While a large number of LC practices can effectively help in overcoming most of the major SC challenges, it was also found that no LC practices can address issues like the lack of interest from the Government and non-availability of strict rules/regulations for SC appliances. While this was disappointing, SC and LC are voluntary and not a regulated activity in construction.

LC implementation status also revealed that the construction industry is struggling with implementing LC in some areas. This applies to some of the common challenges between LC and SC, which implies that more innovative and robust steps will have to be taken as a future research direction.

Theoretically, this study will help the construction industry to understand the concepts and rationale for integrating LC and SC based on their principles and drivers. Practically, the outcomes of this study in the LAST matrix have provided the way forward to the construction industry in overcoming the challenges for implementing SC by utilizing the LC practices.

The results of this study are based on the outcomes of previous literature efforts that has to be verified in the real construction environment for its validity. The capabilities of each of the lean facilitator as presented in the LAST matrix should be confirmed from the inputs of the LC implementing companies and then calibrated by using real project implementation data. This will improve the LAST matrix based on the actual construction environments.

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