U.Porto Journal of Engineering, 5:2 (2019) 29-37
ISSN 2183-6493
DOI: 10.24840/2183-6493_005.002_0004

Received: 6 December, 2018
Revised: 25 December, 2018
Published: 29 November, 2019

Lean Applications in Construction: Review Article

Mohammad Darabseh[1]
[1]Department of Civil Engineering, University of Porto, Porto, Portugal
(darabseh@outlook.com) ORCID 0000-0002-7443-8326

Abstract
Lean Construction is one of the methods used to improve control over construction projects by eliminating waste in time and materials. Lean Construction is an adaptation from the Lean Manufacturing principles to the construction industry.
The purpose of this article was to review the case studies published in 2018 in the Inspec database to find out where Lean is being implemented and how.
The article approach by setting the search criteria first and then inspect the result to find the non-related results and eliminate it. After that, the article was reviewed and summarized.
The article verifies each article finding; however Lean Construction and Building Information Modeling (BIM) are relatively new for the construction industry and they still need more time to be adopted widely and to be applied on a lower-cost budget. However, the discussed cases show a promising future for these technologies.

Author Keywords. Lean Construction, BIM, Last Planner System, RFID, Construction Management.

Type: Review Article
Open Access Peer Reviewed CC BY

1. Introduction

In recent years, Lean is getting more attention from the construction industry. Lean Construction is considered a way to reduce waste in all its forms, such as waste in materials and waste in time. And in order to benefit from that, Pioneers in the construction industry are trying to implement that in their projects. Even though it's still not widely spread among construction to use Lean, the study cases where Lean was implemented show the significance of implementing Lean in a construction project (Sacks et al. 2018). Researchers around the world try to show these cases in their articles. The purpose of this article is to give a clear idea about the domains where Lean Construction is being implemented.

2. Methodology

Construction industry trends such as BIM; Lean; Virtual Reality (VR); Augmented Reality (AR); are being used in new fields continuously. This makes it hard to keep up with the new literature. To make this short, concise and up to date, this review will only contain cases from 2018. The literature is gathered from the Engineering Village database. Engineering Village or Inspec database is an index for the engineering literature from ELSEVIER.

To achieve the objective of this article a search criterion was established as shown in Table 1.

Database:	**Engineering Village (Inspec) by ELSEVIER**
Search keywords:	Lean Construction, Case study
Limitations:	Journal Article, 2018
Search Equation:	(((($Lean $Construction) WN ALL) AND (1896-2019 WN YR)) AND ((($case $study) WN ALL) AND (1896-2019 WN YR))) + ({ja} WN DT) AND ((2018) WN YR)

Table 1: The Article Search Criteria

The total results found were 12. These articles were skimmed to see if they provided enough information about the case study and the way Lean Construction was approached. This approach resulted in the elimination of 6 articles and keeping another 6 articles for further investigation, as shown in Table 2. The reason for eliminating the other articles is that the search formula was applied to "All fields". "All fields" search is more comprehensive, however, the results need to be refined.

	Article Title	Authors
1	The role of formal and informal mechanisms in implementing lean principles in construction projects	Lena Elisabeth Bygballe, Maria Endresen, Silje Fålun
2	Barriers faced by new-adopter of Last Planner System®: a case study"	Athena Maria Perez, Somik Ghosh
3	RFID-Aided Tracking System to Improve Work Efficiency of Scaffold Supplier: Stock Management in Australasian Supply Chain	Sungkon Moon, Shouzhi Xu, Lei Hou, Changzhi Wu, Xiangyu Wang, and Vivian W. Y. Tam
4	Mobile BIM implementation and lean interaction on construction site: A case study of a complex airport project	Ozan Koseoglu, Elif Tugce Nurtan-Gunes
5	Exploring the BIM and lean synergies in the Istanbul Grand Airport construction project	Ozan Koseoglu, Mehmet Sakin, Yusuf Arayici,
6	Using Building Information Modeling to achieve Lean principles by improving efficiency of work teams	Xun Zhang, Salman Azhar, Abid Nadeem & Malik Khalfan

Table 2: List of the reviewed articles

Each article provides data about a certain case study where Lean was implemented. This review will focus on different sections of these articles such as its approach, case study details, and the method of data collection and analysis, in addition to the implications and findings for each article. Articles 5 and 6 were merged under one section because they are about the same construction project: Istanbul Grand Airport.

3. Case Studies Analysis

3.1. Educational Building for Art and Design Case Study

This case study was presented by Bygballe, Endresen, and Fålun (2018). The client for this project was the Norwegian government, presented by the key advisor in public construction and property affairs, and the aim of this project was to build the educational building for art and design. The purpose of the article where this case study was documented was to inspect the effect of formal and informal procedures on implementing Lean concepts in the construction industry. The writers explain they choose the case study for the following reasons:

(1) The project is public which provided easier access for the project documents;

(2) The contractor ambition to use Lean in the project which ensures the commitment to achieve this goal.

The article approach was to use the case to collect qualitative data to reach the paper objectives. The researchers conducted 17 semi-structured interviews with 21 individuals, monitored the project meetings and seminars and casual talks with workers and the project employees. The data collecting method consisted of different methods as follow:

(1) Formal and informal conversations at the company building and in the project site;

(2) Summer internship for two months for one of the authors in the company headquarters to be close to the implementations process;

(3) Participation in Lean related seminars;

(4) Field notes;

(5) Tendering, contractual, evaluation reports project documents.

After that, the collected data was triangulated to ensure data consistency and study quality. The article finds that to have a successful Lean implementation you should have both formal and informal positive involvements. Having a proper contract is important in addition to having a common understanding and trust between the project team. The project delivery method for this project was designed, bid and build (DBB). According to the researcher, using such method for delivery was important to the client to keep the innovation process active, and to help the client keep the project monitored and controlled, in addition to forbidding the contractors from using the traditional methods of work.

The limitations of this case could be constructed as follows:

(1) Lack of experience for the involved individuals from both parties, clients, and contractors;

(2) As Lean was included in the general selection criteria, the client representative had to go through an extensive learning course to be familiar with the process.

3.2. Five-story Educational Building with a Basement Level

This case study was presented by Perez and Ghosh (2018). The client for this project was a state university in the Southern Region of the USA. The project aim was to build a new five-story educational building with a basement level. The purpose of the article where this case study was documented was to assess the Last Planner system (LPS) implementation process in a commercial project and how the Last Planner system is taking over the traditional planning methods. The paper approach toward the case study was to document the Last Planner System implementation process thoroughly without any attempt to evaluate the effectiveness of the advocated practices when implementing the Last Planner system.

The Last Planner system is a technique used to plan production and control it. Results of implementation of Last Planner system successfully showed significant improvement in the project planning, improving performance, in addition to helping make the workflow predictably.

The paper finds that implementing the Last Planner system faces the expected barriers when implementing this system. These barriers were already discussed in the literature and it's considered predictable when it happens to new the Last Planner system adopters especially while they are transitioning from the traditional method of planning. The researchers found from the case study that effective implementation is idealistic. This agreement with the current literature indicates the obstacles facing the teams implementing Last Planner system. In addition to that, project team members are expressing their struggle with the system scheduling method because of the nature of construction projects as they have constraints outside of their control like waiting for Request of Information's (RFIs) response which takes a long time in addition to design changes and its effect on the project schedule.

The limitations according to the article writers, Perez and Ghosh (2018), are that the finding of this article is built on one case study which could not be generalized, however, the article finds matches in the current literature.

3.3. Improving Work Efficiency of Scaffold Supplier by RFID-Aided Tracking System

This case study was presented by Moon et al. (2018). This study is based on the Lean principles, but by taking advantage of technology and information technology. The purpose of the article where this case study was documented, is to give an overview of the self-developed system to track scaffolding with a goal in mind, which improves the productivity. The article approach

toward the case study was to test the tracking system and validate it by experimenting with two streams:

(1) Performance;

(2) Productivity.

In order to validate the developed system, a comparative experiment was conducted, by observing the productivity of work with the developed system and without it.

The developed system requires:

(1) Real-time location system (RTLS);

(2) Active/passive Radio-Frequency Identification (RFID) tag(s);

(3) Wireless sensors;

(4) Single Wi-Fi platform.

The system was built using standard wireless connections which ensure low cost and easiness to connect with the existing wireless local area network (WLAN).

The time spent was measured and then later converted to productivity rates to make the analysis. To investigate the process deeply, it was divided for subtasks as follows:

(1) Ordering;

(2) Planning;

(3) Pre-arranging;

(4) Inspection;

(5) Loading;

(6) Strapping.

These processes were investigated separately, and later, total time was calculated for the process by using the system and without it. The system effectiveness was validated and productive was higher by 11.02% than without using the system.

3.4. Istanbul Grand Airport

Istanbul Grand Airport is the biggest airport in the world. The estimated cost of the project was 10.25 Billion US dollar (Koseoglu, Sakin, and Arayici 2018). The airport opened on October 29, 2018. The airport expected capacity by the end of the last expansion was of 150 million per year. Such mega-scale project gets a lot of attention by researchers and is considered a valuable case study, due to the advanced technology involved, and how this project will affect the construction industry around the world. In this article, the review will focus on two case studies for this airport, which fall in our research limitation. The first case study is on implementing mobile BIM and its interaction with Lean inside the construction site. The second case study explores the BIM and Lean synergies in detail.

This first case study was presented by Koseoglu and Nurtan-Gunes (2018). The purpose of the article where this case study was documented was to assess the benefits of using BIM mobile applications in addition to Lean principles inside a construction site. The article approach toward the case study was to find the added value of using BIM to transform the field for digital data exchange environment. The article finds that implementing BIM mobile technologies and transform the way data is exchanged in the construction site, not just achieve BIM goals, but also Lean goals were also accomplished. The article opens the door for construction project teams in the industry to use BIM outside the office environment where limited tasks could be performed.

The article explores the way the work environment is being transformed from a paper-based work environment to tablet-based work environment. In addition to that, BIM models with construction details help trades workers in the assembly process which accelerate the work-flow and reduce the re-work possible. The data was collected from analyzing the current literature and by analyzing the project documents, and by the authors' personal observations.

The second case study was presented by Koseoglu and Nurtan-Gunes (2018). The purpose of the article where this case study was documented, was to show how BIM and Lean integrate with a mega construction project. The article approach toward the case study was to acknowledge the achieved benefits and improvements in Istanbul Grand Airport as a result of using BIM and Lean. The article finds that implementing BIM with Lean together provided a remarkable result and played a significant role in finishing the first phase of the project on time. In addition to that, BIM and Lean as synergies play a significant role in improving workflow in mega complex projects, such as Istanbul Grand Airport, where international companies are working with local companies and the total number of workers in construction site exceeded 35000 workers. According to the developed evaluation framework by the researchers, they find the following:

(1) Performance and resources management based on BIM systems are tricky and there will be difficulties when used in real projects;

(2) When the project size is big, there will be problems when trying to manage all the resources and performance altogether on a single platform.

3.5. The Martin Army Community Hospital

This case study was presented by Zhang et al. (2018). The client for this project was the US Army Corps of Engineers. The intention of this project was to build The Martin Army Community Hospital in Fort Benning, located in the Georgia State, in the Southeastern region of the USA. The project delivery method was Design-Build and the general contractor was Turner Construction. The total contract cost was approximately 333 million US dollar. The project started in August 2011 and finished in July 2014. The purpose of the article where this case study was documented, was to prove that BIM can achieve the Lean principles by improving the productivity of construction projects. The article approach toward the case study was to establish some metrics to measure the BIM effect in achieving Lean principles. These metrics were:

(1) Hours of re-work;

(2) Physical conflicts;

(3) Request for information's;

(4) Change orders;

(5) Prefabrication;

(6) Cost saving;

(7) Schedule compliance.

The article finds that using BIM in the project has the following effects:

(1) Improve coordination among the project team;

(2) Open the door for using prefabrication in more areas of the construction project;

(3) Ensure a higher level of safety;

(4) Reduce inventory;

(5) Avoid time-consuming activities such as re-work.

The case study authors summarize their findings as follows:

(1) Using BIM and Lean practices reduced the cycle time for RFIs where the average RFI cycle time was 2 weeks and after using BIM and Lean was reduced to 2-3 days;

(2) BIM increased the prefabrication percentage with the following percentages (50% in the electrical part, 75%–80% HVAC system and 40%–50% Plumbing system);

(3) Using Robotic layout for locating building components is effective and fast up the installation process four times more than using the traditional method;

(4) BIM is remarkable to reduce clashes which made the project team confidante and saved them time and re-work;

(5) BIM is remarkable to reduce waste, which means that by using it, Lean is already being implemented;

(6) Using a BIM model on site made the information exchange process faster and facilitate the BIM coordination process.

4. Discussion

Based on the reviewed case studies, we noticed that Lean philosophy is still not adopted widely and it's limited to projects that were considered mega sized and when investors ask for Lean to be used. However, as shown in the map in Figure 1 below, the reviewed projects are also distributed around the world, which shows a big interest in such technology.

Figure 1: Map showing the countries in yellow where the case studies where carried out

The cases also show the global interest in finding out more about where Lean in construction could help and this is shown in the diversity of themes where Lean was implemented. Themes are summarized in Figure 2.

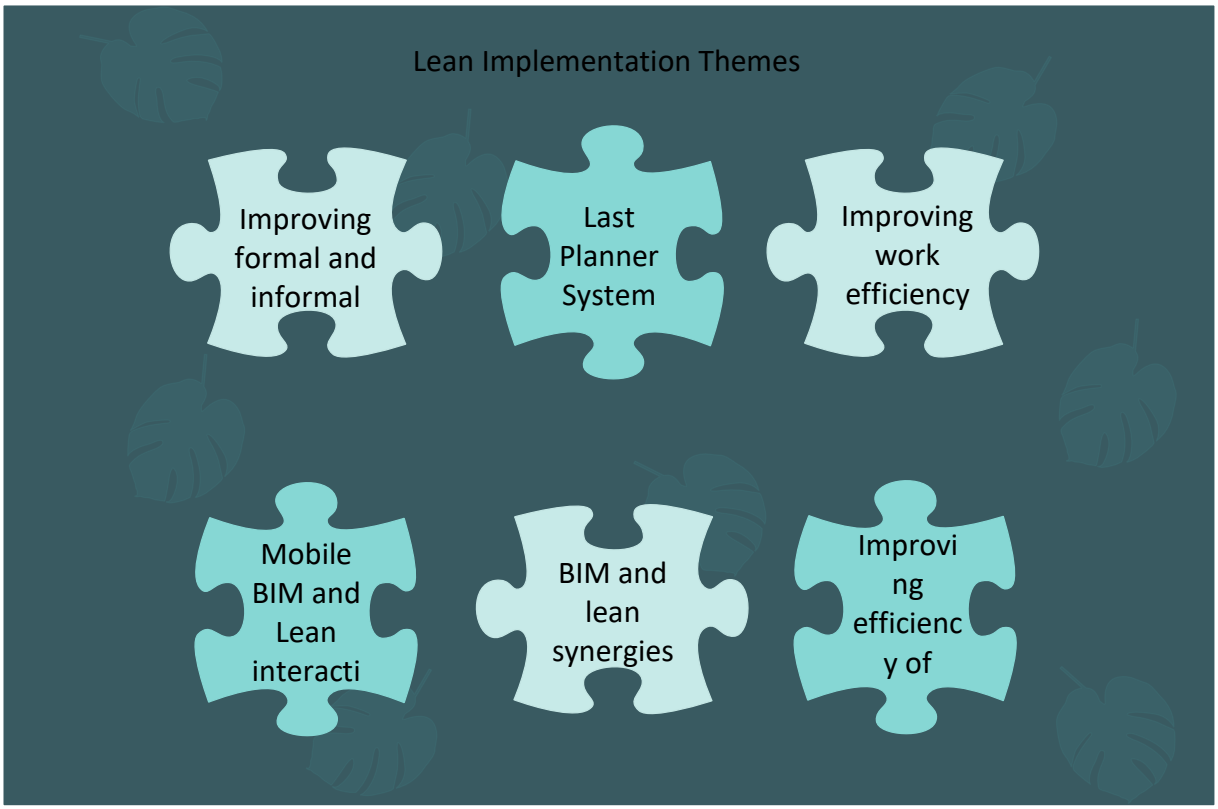

Figure 2: Lean Implementation Themes

5. Conclusion

This paper report findings from multiple case studies for implementing Lean principles in the construction industry.

Each case study provides different aspects for approaching Lean in construction and with every approach we reach unique and specific conclusions, although, in the end, all these secondary conclusions belong to the original Lean principles.

About the Educational Building for Art and Design, the case study focused on implementing Lean concepts in the formal and informal procedures in the construction industry. The article shows the significant role mechanisms play in the Lean implementing process. In this case, the client and the contractor team influenced the whole process positively by implementing the formal mechanisms from the beginning in tendering and after that, in the contracting and later in the structural interventions. Furthermore, the stockholders paid attention to the informal mechanisms such as lateral relationships and trust. This affected the process of implementing Lean positively. Focusing on informal mechanisms is a smart move, instead of depending on unplanned thriving for these mechanisms. In this way, the mechanisms will evolve progressively in parallel with formal mechanisms.

About the Five-story Educational Building with a Basement Level case study, this is focused on assessing the Last Planner system implementation process in a commercial project and how Last Planner system will take over the traditional planning methods. The first goal for the team was to start using the LPS weekly planning, which they face many problems using it for look-ahead planning and root-cause analysis. And even though the project team was following the implementation strategy, however, they did not have a clear understanding of it. They were just following the company upper management when they ask them to move for the next step in the strategy. This means that the adopted implementation strategy is not effective and does not serve the purpose of developing it. And that is because it does not consider the team level

of knowledge, which caused confusion and ambiguity for the team. Also, that made the team less aware of everyone responsibilities. In addition to that, the researchers noticed that the point of contact between the Last Planner system and the trades workers were the superintendents, which is a good thing that they can be involved in the process. However, this ignores the superintendent's workload. Therefore, the Last Planner system implementation process should be led by the project manager with help from the project team. From this case study, it is obvious that effective implementation is not easy and not reachable yet. In order to facilitate this process, the literature and the researchers recommend having a Lean champion.

A Lean champion has extensive knowledge and expertise about Lean and its implementation process. They also suggest an incremental strategy for implementing Lean. Furthermore, the Last Planner system should be implemented with other companions' systems to cover the sides that Last Planner system does not cover, for example, the Last Planner system doesn't cover the problems that show from the project design office.

About the Improving Work Efficiency of Scaffold Supplier by RFID-Aided Tracking System case, this focuses on a self-developed system to track scaffolding with a goal in mind, which improves the productivity based on Lean principles. The article aimed to eliminate the elements that reduce productivity in the process. The system was successful in tracking each object, which resulted in higher productivity in each task.

About the first case regarding Istanbul Grand Airport, focused on assessing the benefits of using BIM mobile applications in addition to Lean principles inside a construction site, this article provides a new approach because it focuses on BIM outside of the design office to introduce a digital construction site. Using BIM on-site improve the project management practices in addition to achieving the Lean principles.

About the second case regarding Istanbul Grand Airport, it focuses on how BIM and Lean integrate into a mega construction Project. Nowadays BIM is vital for a construction site for projects in Istanbul Grand Airport. Lean Construction is also crucial for achieving the project goals which summarize in:

(1) Reducing project costs;

(2) Eliminate waste in the project;

(3) Deliver the project on time.

BIM was used in the project for the following reasons:

(1) Intelligent design review;

(2) Documents coordination;

(3) Change control;

(4) Improve the project communication and its supply chain;

(5) Prepare Istanbul Grand Airport for facility management phase which is essential for the project life cycle.

Istanbul Grand Airport, by merging BIM and Lean will make the future vision for working with these technologies together clear and more understandable.

About the Martin Army Community Hospital, which focuses on how BIM technology can achieve the Lean principles by improving the productivity of construction projects, in this project, BIM performed as a communication platform for the project team. The result of that was:

(1) Improve the coordination. Quality;

(2) Improve work efficiency.

In total, BIM made the project workflow faster. To sum-up, Lean Construction and BIM are relatively new for the construction industry and they still need more time to be adopted widely and to be applied on a lower-cost budget. However, the discussed cases show a promising future for these technologies.

Bibliography

Bygballe, L. E., M. Endresen, and S. Fålun. 2018. "The role of formal and informal mechanisms in implementing Lean principles in construction projects". *Engineering, Construction and Architectural Management* 25, no. 10 (november): 1322-38. https://doi.org/10.1108/ECAM-07-2017-0138.

Koseoglu, O., and E. T. Nurtan-Gunes. 2018. "Mobile BIM implementation and Lean interaction on construction site: A case study of a complex airport project". *Engineering, Construction and Architectural Management* 25, no. 10 (november): 1298-321. https://doi.org/10.1108/ECAM-08-2017-0188.

Koseoglu, O., M. Sakin, and Y. Arayici. 2018. "Exploring the BIM and Lean synergies in the Istanbul Grand Airport construction project". *Engineering, Construction and Architectural Management* 25, no. 10 (november): 1339-54. https://doi.org/10.1108/ECAM-08-2017-0186.

Moon, S., S. Xu, L. Hou, C. Wu, X. Wang, and V. W. Y. Tam. 2018. "RFID-aided tracking system to improve work efficiency of scaffold supplier: Stock management in Australasian supply chain". *Journal of Construction Engineering and Management* 144, no. 2 (february): Article 04017115. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001432.

Perez, A. M., and S. Ghosh. 2018. "Barriers faced by new-adopter of Last Planner System®: A case study". *Engineering, Construction and Architectural Management* 25, no. 9 (october): 1110-26. https://doi.org/10.1108/ECAM-08-2017-0162.

Sacks, R., C. Eastman, G. Lee, and P. Teicholz. 2018. *BIM Handbook: A guide to Building Information Modeling for owners, designers, engineers, contractors, and facility managers*. Wiley. https://doi.org/10.1002/9781119287568.

Zhang, X., S. Azhar, A. Nadeem, and M. Khalfan. 2018. "Using Building Information Modelling to achieve Lean principles by improving efficiency of work teams". *International Journal of Construction Management* 18, no. 4 (july): 293-300. https://doi.org/10.1080/15623599.2017.1382083.