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OFF-SITE CONSTRUCTION COMPANY LEAN MATURITY ASSESSMENT USING DOLC

Gabriel Da Silva Macêdo[1], Priscila Mirapalhete Rodegheri[1], Lucas Broggio[1], Gabriel Vieira Pinheiro[1], Itamar Aparecido Lorenzon[2], Sheyla Mara Baptista Serra[2]

ABSTRACT

The Architecture, Engineering, Construction, and Operation (AECO) industry have to reduce material consumption and eliminate waste. Regarding this, Lean Construction (LC) has emerged as an efficient tool. The company LC maturity level must be measured to evaluate its effectiveness and then to improve its implementation. Therefore, this paper aims to assess the lean maturity of an off-site light gauge steel frame construction company. The maturity model applied was Degree of Lean Construction (DOLC) for this case study, because this model is better fitted for the Brazilian AECO industry scenario. After that, the results were compared with related publications. The analyzis showed 65% maturity for the current case study, characterizing it as Level C of maturity in lean construction, higher than another's publications. The results indicate that the company have a better LC maturity than other ones found in publications due to the synergy between the off-site construction and Lean principles, even without intentional LC adoption.

KEYWORDS

Lean construction, off-site construction, maturity models, light gauge steel frame, industrialization.

INTRODUCTION

According to the Net Zero by 2050 Program (United Nations Environment Program - UNEP, 2024), there is a necessity to rethink material consumption and to reduce waste in construction. To meet that, the Lean Construction (LC) focused on construction management has been growing (Daniel *et al*., 2024; Vaidyanathan et al., 2024). However, many companies have not yet implemented LC management strategies because they do not understand their benefits (Lin et al., 2022).

To better understand the efficiency of the adopted management strategies, many companies seek to measure the maturity level of their operations, making it essential to understand the current level of adoption, opportunities for improvement, business development, and sustain the application of the adopted strategy to meet the company's

[1] Programa de Pós-graduação em Engenharia Civil – Universidade Federal de São Carlos (UFSCar)
[2] Departamento de Engenharia Civil – Universidade Federal de São Carlos (UFSCar)

objectives (Jia et al., 2013; Crosby, 1986; Garza-Reyes, 2018; Vaidyanathan et al., 2024). The maturity assessment system for the company management must be appropriate to itself. For LC maturity assessment, several Maturity Models (MM) have been developed, such as those presented by Hofacker et al. (2008), Carvalho and Scheer (2017), Nesensohn (2017), and Soto Becerra (2016).

Some strategies, such as industrialization, are important for reducing waste, where activities are operated in a controlled location instead in the construction site. Off-site construction is one alternative for industrialization and emerges as an innovative approach in which construction components are manufactured in a factory environment, resulting in better quality control, waste reduction, greater standardization, and more efficiency (Jin et al., 2018; Aburas, 2011). Through this method, the precision of elements can be increased and their assembly speed reduced in the construction site. Thus, it ensures high-quality production, reducing construction time and on-site operation costs (An et al., 2020; Arashpour et al., 2019).

Off-site construction methods, such as light gauge steel frame, can reduce buildings carbon footprint, one of the objectives included in Net Zero by 2050 (Daniel *et al*., 2024; UNEP, 2024). This constructive system has a reduced material waste and energy consumption during construction (Iuorio, Gigante & De Masi, 2023). Therefore, off-site construction combined with LC, is an assertive strategy for construction efficiency, reducing non-value-adding activities, and optimizing cycle time while improving product quality, labor productivity, and process efficiency (Broadhead *et al*., 2023; Daniel et al., 2024; Daniel & Oshodi, 2022; Goh & Goh, 2019).

In this context, this paper presents the lean maturity assessment through the Degree Of Lean Construction (DOLC) MM (Carvalho, 2008) of a company that supplies off-site construction systems through light gauge steel frame. The DOLC is established in LC bibliography, well known in Brazilian construction community and it evaluates different types of stakeholders and provides a broad comprehension about the company maturity as a hole (Carvalho & Scheer, 2017; Rodegheri & Serra, 2020; Ferreira et al., 2021).

This research aims to evaluate the necessary adaptations to implement DOLC in an off-site construction company, considering that this MM was not created for this specific context. Moreover, the results of the off-site company, that does not formally apply LC, will be compared with results of other research that utilized DOLC, and verify if industrialized processes results in a better level of LC maturity in this company, even though it not formally adopted. The literature shows many MM for LC, therefore LC MM for off-site construction are scarce (Broadhead *et al*., 2023; Daniel *et al*., 2024).

Furthermore, Brazil was chosen as the focus of this study due to the specificities of the country's construction sector, which presents distinct challenges compared to the other markets. Unlike countries with higher level of adoption of industrialization in construction, Brazil still characterized as traditional building construction methods, low standardization, and difficulties in implementing Lean strategies due to cultural and structural barriers (Carvalho & Scheer, 2017; Mano *et al*., 2022). This study seeks to explore these adaptations to apply DOLC in an off-site construction company and analyze how industrialization can influence Lean maturity, considering the particularities of the Brazilian market and its opportunities for evolution. Besides this, it aims to present the necessary adjustments for DOLC application to measure the maturity level of off-site constructions, turning it closer to the manufacture reality (Broadhead *et al*., 2023).

METHODOLOGY

This paper adopts qualitative exploratory analyzis combined with a case study as a research strategy to achieve the proposed objectives (Yin, 2003; Ketokivi & Choi, 2014). The case study is organized into three stages: Preparation, Organization, and Report (Elo & Kyngäs, 2008). In the Preparation stage, a literature review was conducted on suitable MM for LC and the correlation of LC with off-site construction, aiming to address the challenges of Net Zero by 2050 (UNEP, 2024). In this stage, the DOLC MM was selected for application in the case study due to its well-known adoption in Brazil, the location where the case study was conducted (Carvalho & Scheer, 2017; Direitinho et al., 2014; Rodegheri & Serra, 2020; Ferreira et al., 2021). The organizational stage consisted of a selection of a company that adopt off-site construction, site visits, conduction of a study through the DOLC application in the selected company, and consolidation of the obtained results. In the Report stage, the data collected from the company were grouped, discussed, and compared with literature data about off-site construction and DOLC uses; the particularities of each case were discussed, and conclusions were structured for report preparation.

THE DOLC MM

The DOLC was developed by Carvalho (2008) and applied by several Brazilian researchers since its publication. This MM consists of six questionnaires to evaluate the adoption of the eleven LC principles proposed by Koskela (1992), presented in Figure 1c. Each questionnaire is made for different stakeholders involved in the project: Director, Engineer, Worker, Client, Supplier, and Designer. The six questionnaires have the same structure, but the questions are contextualized to each stakeholder. To this MM all questioners have the same weight to compose the company evaluation as well as each question and principle have the same weight to each other.

The questions are open-ended, and the stakeholders must answer the company's degree of adherence on a Likert scale from zero to three, as zero equivalent to no principle applied and three to full principle applied, as shown in Figure 1a. With the values of each principle, the average is calculated to determine the maturity level of each one. Finally, the average of the principle is calculated to characterize the company's maturity level and transformed into percentage. The results are presented in a radar chart format and classified into four levels and twelve sublevels, the higher level is named A and the evaluation range is from 85% to 100%. The lower level is named D and the evaluation range is from 0% to 54%, as shown in Figure 1b.

In the Brazilian context, Carvalho's (2008) tool, called DOLC, is widely used (Carvalho & Scheer, 2017). DOLC's usage fits on companies that formally adopt LC, companies pretending to start their lean journey, or companies that do not adopt some specific management system but participate in the national research scenario (Carvalho & Scheer, 2017; Rodegheri & Serra, 2020; Ferreira et al., 2021). Table 1 presents data compilation from three references that applied DOLC in Brazilian construction companies located in São Paulo state.

a)

QUESTIONS EVALUATION			
0	1	2	3

b)

PRINCIPLES AND FINAL EVALUATION			
LEVEL	SUB LEVEL	GRADE	DOLC CLASSIFICATION
A	AAA	95% a 100%	VERY GOOD LEVEL OF LEAN CONSTRUCTION
	AA	90% a 94%	
	A	85% a 89%	
B	BBB	80% a 84%	GOOD LEVEL OF LEAN CONSTRUCTION
	BB	75% a 79%	
	B	70% a 74%	
C	CCC	65% a 69%	LOW LEVEL OF LEAN CONSTRUCTION
	CC	60% a 64%	
	C	55% a 59%	
D	DDD	50% a 54%	NO USE OF LEAN CONSTRUCTION
	DD	45% a 49%	
	D	0% a 44%	

c)

NUMBER	PRINCIPLE
1	Reduction of non-value-adding activities
2	Improve product value through systematic consideration of customer requirements
3	Reduce variability
4	Reduce cycle time
5	Simplify and minimize the number of steps and parts
6	Enhance product flexibility
7	Improve process transparency
8	Focus on global process control
9	Introduce continuous process improvement
10	Balance flow with conversion improvements
11	Benchmarking (establishing leading-edge references)

Figure 1: Values for evaluating questions, maturity classification, and principles adopted by MM DOLC (own elaboration).

Table 1: Results of studies that applied DOLC (own elaboration).

Author	Company description	Actors	Actor results	Overall Result
Direitinho *et al*. (2014)	Does not apply LC Medium-sized company (30 years in construction) Ribeirão Preto - SP Commercial and residential construction (multifamily)	Directory	60,61	63,17%
		Engineer	66,41	
		Worker	53,79	
		Client	65,10	
		Supplier	58,38	
		Designer	74,75	
Rodegheri & Serra (2020) (Own data)	Does not apply LC Small-sized company (5 years in construction) Sorocaba - SP Commercial, residential (single-family) and industrial construction	Directory	39%	56%
		Engineer	49%	
		Worker	68%	
		Client	59%	
		Supplier	-	
		Designer	66%	
Ferreira *et al*. (2021)	Does not apply LC Small-sized company (6 years in construction) Ribeirão Preto - SP Commercial and residential construction (single-family)	Directory	77	55%
		Engineer	42	
		Worker	60	
		Client	36	
		Supplier	58	
		Designer	57	

The company analyzed by Direitinho et al. (2014) is a medium-sized company with 30 years of experience in the market. This company works with vertical and horizontal condominiums and allotment developments, thus implementing intentional standardization and repeatability among projects on a large scale. The company analyzed by Rodegheri & Serra (2020) is a small-sized enterprise; however, some residential projects are multi-family, thus showing adoption of intentional standardization and repeatability. With the lowest level of maturity among the other studies, the company analyzed by Ferreira et al. (2021) is a small family business that works with commercial and single-family residential construction projects, which does not adopt intentional standardization or repetition between different executed works.

CASE STUDY

The Case Study consisted of applying the MM DOLC in a small-sized company (annual revenue of R$3,600,000.00; Brazilian currency) which started to operate in May 2022 in São Carlos City, state of São Paulo, Brazil. The company operates in the industrial construction sector, producing steel frame profiles, developing custom projects, and manufacturing light gauge steel frame structures.

It does not formally adopt lean principles, however, it adopts off-site construction, producing standardized elements manufactured on a large scale and engineer-to-order (ETO) project elements. The ETO production is the one assessed in this research. The industry only produces the structure of light gauge steel frame to meet the client design. The company deliver the frames, and the client is responsible to assemble it and apply the finishing to meet the design project. Thus, the company is not responsible for the assembly or subsequent activities carried out on site.

The interviews were conducted in November and December 2024 by researchers, with five stakeholders interviewed, who's their characteristics are presented in Table 2. The only external stakeholder interviewed was supplier, who supplies the main raw material used by the company. It is worth mentioning that it was impossible to interview the client because they did not answer the contact attempts until March 2025.

Table 2: Stakeholders characterization (own elaboration).

Stakeholders	Director	Factory Engineer	Factory Worker	Supplier	Manufacturing Designer
Position	Director	Industrial coordinator	Operator 2	Sales representative	Júnior engineer
Academic background	Administration	Production Engineer	High school	Enterprise administration	Civil Engineer
Age	34 years	56 years	39 years	39 years	24 years
Professional experience	7 years	23 years	20 years	4 years	1,5 years
Company experience	4 years	3 years	2 years	4 years	1 year

Their company adopts off-site construction and that the DOLC questionnaire was developed for traditional construction companies (i.e., those that do not adopt industrialized systems), some adaptations had to be made regarding the context of agents and adopted terms. Table 3 compares the original model proposed by Carvalho (2008) and the adaptations made in this work, highlighted in underlined text.

Table 3: Adaptations for DOLC application in industrialized companies (own elaboration).

Comparative	Original (Carvalho, 2008)	Adaptations
Actors/stakeholders: it was necessary to adapt the nomenclature of some actors to characterize them more adequately	Director	Director
	Engineer (construction)	Engineer (factory)
	Worker (construction)	Worker (factory)
	Client	Client
	Suppliers	Supplier
	Construction designer	Manufacturing designer
Terms: it was necessary to adapt or replace terms to make the questionnaire compatible with industrialization	Construction	Factory
	Construction site	Production line
	Construction planning	Production planning
	Construction budget	Production budget
	Productivity of construction workers	Productivity of production workers

RESULTS

The results are presented in radar charts and summary tables. The radar charts in Figures 3 to 7 show the assessments of the five interviewees, while Figure 8 presents the company's overall lean maturity average according to DOLC. In the charts, it is possible to identify the evaluated principles, numbered from 1 to 11, the evaluation scale in background colors according to Figure 1, the percentage of adherence assigned to each factor next to the principle number, represented by the filled grey area in the chart, and the final average for each interviewee and company, indicated in the legend.

Table 4 shows the overall summary of each stakeholder and company evaluation and the comparative assessment by the principle of the company's overall average and each interviewee.

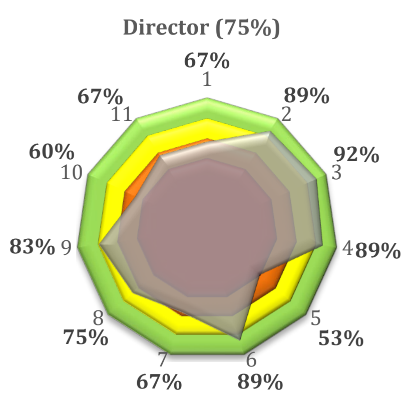

Figure 3: Director evaluation with DOLC method (own elaboration).

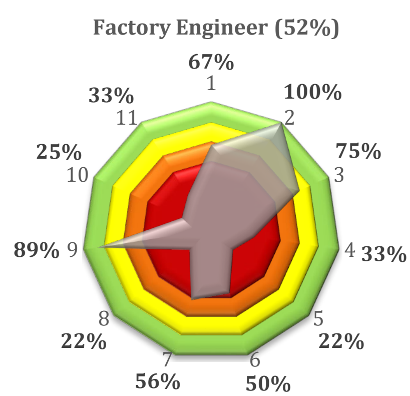

Figure 4: Factory Engineer evaluation with DOLC method (own elaboration).

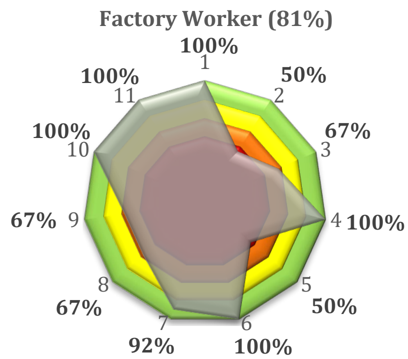

Figure 5: Factory Worker evaluation with DOLC method (own elaboration).

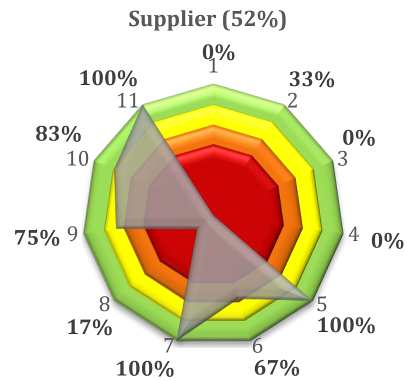

Figure 6: Supplier evaluation with DOLC method (own elaboration).

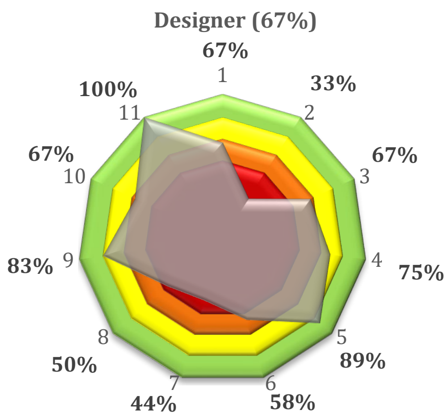

Figure 7: Designer evaluation with DOLC method (own elaboration).

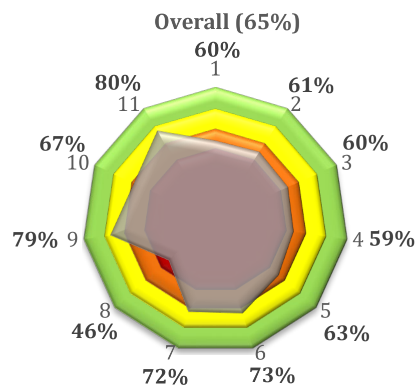

Figure 8: Overall company evaluation with DOLC method (own elaboration).

Table 4: Summary of DOLC CE application results (own elaboration).

	Company Characterization	Actors	Actors' results	Overall result
Case Study Industrialized enterprise	Does not apply LC Small-sized company (3 years in operation) São Carlos - SP Light gauge steel frame commercial and residential constructions	Director	75%	65%
		Factory Engineer	52%	
		Factory Worker	81%	
		Supplier	52%	
		Designer	67%	

According to the results shown in Figure 8 and Table 4, the company in this case study showed a final score of 65% in Lean maturity through the DOLC model, classified as Level C, with a low level of LC. Table 5 presents the results of the company and for each stakeholder through LC principles, in descending order, that is, from the most met principle (benchmark with 80%) to the least met principle (focus control on complete process with 46%).

Table 5: Summary for each LC/DOLC principle (own elaboration).

	LC/DOLC Principle	Overall	Director	Factory Engineer	Factory Worker	Supplier	Designer
11	Benchmark	**80%**	67%	33%	100%	100%	100%
9	Build continuous improvement into the process	**79%**	83%	89%	67%	75%	83%
6	Increase output flexibility	**73%**	89%	50%	100%	67%	58%
7	Increase process transparency	**72%**	67%	56%	92%	100%	44%
10	Balance flow improvement with conversion improvement	**67%**	60%	25%	100%	83%	67%
5	Simplify by minimizing the number of steps, parts, and linkages	**63%**	53%	22%	50%	100%	89%
2	Increase output value through systematic consideration of customer requirements	**61%**	89%	100%	50%	33%	33%
1	Reduce the share of non-value-adding activities	**60%**	67%	67%	100%	0%	67%
3	Reduce variability	**60%**	92%	75%	67%	0%	67%
4	Reduce the cycle time	**59%**	89%	33%	100%	0%	75%
8	Focus control on the complete process	**46%**	75%	22%	67%	17%	50%
	Average	**65%**	**75%**	**52%**	**81%**	**52%**	**67%**

Legend: Levels of Lean Construction (LC)
Very Good   Good   Low   No Use

DISCUSSION

The distribution of the overall result indicates a focus on industrial production processes since, except for principle 6, all the values above the average consider internal manufacturing processes. When analyzing these results by the interviewee, the factory engineer had an average assessment below the overall, with only one value above the overall. This may suggest that his academic background and previous experience provide him with a leading-edge reference from other industries, which could offer insights for improvement to the company. This does not, however, indicate that the maturity level is low, it simply demonstrates different goals conditioned by the level of knowledge.

Looking at the results of the below overall averages principles by the interviewee, the supplier's responses stand out, scoring 3 principles with zero, contrasting with other interviewees. This may be related to a skewed perspective due to the difference between the supplier company's experience (62 years) and the length of their contract with the company under study (4 years). It is possible that the supplier company's maturity level is higher than the company in this study, and their evolution has been constant and slow, creating for this agent a fake impression that the maturity level of the company under study is low.

For principle 8, there is a discrepancy between the director's response and that of the other interviewees. This distinction may indicate the lack of global process control tools that provide transparency and prevent all employees from accessing company information, meaning that only a few people retain information. An example is the absence of a daily schedule of activities, as the factory engineer defines daily activities and verbally passes them to the workers.

Although the overall graph shows a balanced distribution of principles evaluation, there is a significant opposing imbalance between the maturity graphs by the interviewee, demonstrating variability among individual results. This may be related to academic background level, years of experience, or how each person interprets lean concepts within their area of expertise.

Analyzing the company's overall lean maturity score concerning the general average for each stakeholder, it is observed that the Factory Worker had the highest score, followed by the Director and Designer, all above the company average. In contrast, the Factory Engineer and Supplier scored significantly below the company's average. The Production Worker is the one with the lowest academic education, and the Director and Designer are the least experienced, which may indicate a lack of understanding regarding the growth potential of Lean characteristics.

Comparing the results obtained in this work, presented in Table 4 with the results from other studies, presented in Table 1, it is observed that the company under study has a higher lean maturity level than the others. Given that none of the companies in these studies formally adopts LC, the particularities of each case study directly impact their respective maturity level. The company analyzed in this study uses off-site construction and have no scope in the installation of the structure on-site. Even though, there is a comparison of the LC maturity in this industry and in on-site results, and that demonstrated greater lean maturity; it shows that using off-site construction technology increases the adoption of standardization and repeatability (Daniel et al., 2024; Broadhead et al., 2023) but it's necessary to have the on-site interviews results, so the comparison will be complete.

It is observed that the higher degree of specialization, standardization, and repeatability, the greater lean maturity, even if the company does not formally adopt LC. Companies that adopt off-site methods, have repeatable projects, invest in developing design, assembly, execution solutions, planning, and product development, ensures higher productivity and agility in service completion. Furthermore, industrialization promotes greater quality control at all production stages and reduces the risk of on-site construction errors by addressing problems at their root cause and reducing steps and cycle time (BROADHEAD et al., 2023).

Throughout the interview, it was possible to identify some deficiencies and incompatibilities in the DOLC method when applied in an industrial context. The most notable aspect is that repetitive and technological work requires fewer tools and different types of controls, which are usually performed by machine sensors (with data also being processed by the machine itself). An example is the factory replacement of the term man-hour (commonly used in construction) for the term machine-hour, which is counted and provided by the equipment. Additionally, since the factory works with products of low variability and high technological control, there is no need to use prefabricated products, kits or place small inventories throughout the factory, as the product and raw materials undergo with minimal variation.

CONCLUSION

Once again, LC is a tool for the construction industry to advance in its management, even when adopted unintentionally. In this work, it was possible to observe that the MM DOLC needed adaptation for the industry context; therefore, it was a valid tool for measuring the lean maturity level in industrialized construction company when adequately adapted. However, it is essential to emphasize that in this research, the interviewees belonged to the company's manufacturing/production stage, and no interviews were conducted at the construction site.

Also, it was possible to verify that, compared to results from the literature, the maturity of this case study was higher for DOLC results. Therefore, it can be concluded that companies that adopt industrialized and off-site construction systems can develop higher lean maturity than construction companies that adopt traditional systems, even if this adoption is not intentional. This may happen due to the existing synergy between LC and the need for repetition, standardization, project detailing, reduction of steps, tool improvement, and cycle reduction.

The main limitations of this research can be grouped into four aspects. Firstly, the sampling limitations, as the study was conducted in only one light gauge steel frame industry, making it impossible to compare with other industries in the same segment and companies that use different industrialized construction methods. Secondly, the methodological limitations, since DOLC was developed initially for traditional construction companies, and it was required to make adaptations for application in industrialized companies. Thirdly, the temporal and geographical limitations, as the research represents a momentary snapshot of a company with three years of operation, located in São Carlos - SP, without comparison to similar companies from other regions. Finally, the perceptions of those evaluated may be influenced by their previous experiences and current activities.

Finally, there is a need to dive into the knowledge about LC MM for industrialized companies. Therefore, the following suggestions for future research are proposed: a) adaptation of DOLC for industrialized companies or development of LC MM focused on these construction systems; b) application of questionnaires in industrialized construction sites and comparison with industry results, especially for construction and factory engineers, construction and factory operators, and manufacturing and civil designers; c) further study of the design interface developed for industry and construction within off-site construction systems.

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