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THE SYNERGIES BETWEEN LEAN AND BIM: A PRACTICAL AND THEORETICAL COMPARISON

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ABSTRACT

Lean and BIM combined have proven to positively impact productivity in the construction sector. This paper aims to identify how the synergies between Lean and BIM have been happening in practical and real-life applications and compare them with the Sacks et al. (2010) matrix, using the information on processes of Brazilian construction companies that work with Lean and BIM. We carried out semi-structured interviews with three construction companies to identify the interactions between Lean and BIM in their processes. As a result, we identified synergies in both Sacks et al. (2010) and the construction companies' practices; other synergies were identified only in Sacks et al. (2010), while others were identified only in the companies interviewed. These new interactions may be due to the technological advances during the last decade that made possible new uses of BIM or the level of implementation of Lean and BIM by companies, amongst other factors. This work contributes to technical and scientific knowledge since it brings a practical view of a topic that has a more theoretical approach. With the results, we can indicate the more common interactions to be implemented by companies, creating a safer way to be followed by companies seeking to implement Lean and BIM.

KEYWORDS

Building Information Modeling, Lean Construction, BIM and Lean Interaction Matrix, synergy.

INTRODUCTION

Compared to other industries, the civil construction industry has low productivity (Heigermoser *et al.*, 2019). Even though it is still considered an industry not technologically advanced, scholars have studied topics such as waste reduction, processes improvement, and information virtual flow in the past decades.

Among these topics, two essential concepts have been developing since the ’90s and have significant impacts when delivering construction projects. The first topic is Lean Construction, a production management philosophy adapted to construction and derived from the Toyota Production System (TPS) (Comelli, 2017). The second topic is Building

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Information Modelling (BIM), which has the potential to transform the use of information technology in the construction industry (Tezel et al., 2020; Greenwood et al., 2017).

According to Dave et al. (2011), there are two types of problems associated with construction: a) construction processes problems; and b) product representation problems. Lean Construction offers an effective way to solve construction processes problems, while BIM help to solve many of the problems related to projects (products) by providing visualization tools and intelligent product models based on a virtual platform. Because of that, these topics have been more developed and studied.

Oskouie et al. (2012) indicate the necessity to explore the interactions between Lean and BIM through practical and real-life application of such synergies. Seeking to supply the absence of data on how these synergies have been applied in real life, this paper aims to identify the synergies that happen in construction companies that already use Lean and BIM but do not necessarily use them in an integrative way.

Thus, this study sought to compare the findings of Sacks et al. (2010) with Brazilian construction companies' practices to understand which synergies the construction companies achieved and which identified synergies could be considered new.

LITERATURE REVIEW

Al Hattab & Hamzeh (2015) defend that BIM and Lean are synergic practices. BIM functionalities support Lean Principles and vice-versa, having a synergic effect (Dave et al., 2011). However, BIM and Lean have been used separately to increase general productivity and the civil construction industry's efficiency (Heigermoser et al., 2019).

Despite being different, independent, and separate concepts, BIM and Lean can obtain their maximum benefits via simultaneous implementation, especially when their adoption is through Integrated Project Delivery (Sacks et al., 2010; Greenwood et al., 2017).

The number of researchers seeking to understand Lean and BIM synergy has been rising: Mellado & Lou, 2020; Schimanski et al., 2020; Bataglin et al., 2020; Tezel et al., 2020; McHugh et al., 2019; Dave et al., 2015; Dave et al., 2013; Oskouie et al., 2012.

BIM enables error detection, omissions, and clashes beforehand, which helps reduce waste and makes construction processes more linear (Eldeep et al., 2022). Bayhan et al. (2021) state that companies that wish to improve their production processes should invest as a priority in Lean and BIM to eliminate waste such as rework, time, and cost losses.

In their research, Dave et al. (2011) noticed that the interactions/synergies between Lean and BIM are found throughout the project life cycle, having powerful interactions in the construction phase. Thus, there is a potential to develop a system that integrates Lean with the rich information model provided by BIM. For Mollasalehi et al. (2018), BIM and Lean integration improve productivity and global performance. Therefore, there is an increased level of adoption of these two approaches in the construction industry.

RESEARCH METHOD

This paper proposed a qualitative research method through a case study to identify the existing synergies between Lean and BIM in Brazilian construction companies that already use such approaches. We chose a case study as a research strategy since researchers do not have control over behavioral events, and the research focuses on contemporary events. In addition, the case study provides a wide range of the studied object and allows a broad and detailed knowledge about it (Yin, 2015). We carried out semi-structured interviews with representatives responsible for implementing or using

Lean and/or BIM in the companies that participated in the study. With these interviews, we aimed to verify if these companies are using Lean principles and BIM functionalities combined and how this correlation is inserted in their processes.

We developed the interview script based on Sacks et al. (2010). We carried out a pre-test of the interview script with the technical director of a consulting firm that provides construction management solutions. The script dealt with BIM implementation, Lean implementation, obstacles, and gains obtained using these approaches. We also discussed the company's vision regarding BIM and Lean synergy, how it happens in practice, BIM functionalities, and how they help apply a Lean principle in a more specific fashion.

Three Brazilian companies that use both Lean and BIM participated in the study: two located in the State of Ceará and one that works nationwide, based in São Paulo.

We carried out six remote interviews in total, two in each company. We interviewed technical directors and professionals who worked in BIM and/or Lean sectors. From their answers, we identified the existing synergies throughout the life cycle of the companies' works. These synergies could be positive or negative when BIM helps or harms the use of Lean and vice versa, respectively.

The identified synergies were compared with those presented in the Sacks et al. (2010) matrix. In the matrix (Figure 1), we identified four classes of synergies:

a) Common synergies: refer to the synergies found in all interviewed companies and Sacks et al. (2010) matrix.
b) Partial synergies: refer to the synergies found in at least one of the interviewed companies and Sacks et al. (2010) matrix.
c) Empirical synergies: refer to synergies found in at least one of the interviewed companies and not in Sacks et al. (2010) matrix.
d) Matrix synergies: refer to synergies found only in Sacks et al. (2010) matrix but were not identified in the interviewed companies.

RESULTS AND DISCUSSION

Company Alpha has been implementing Lean since 2004 and has been developing practices and tools that nowadays are embedded in the company's management culture. BIM was first implemented in 2014, especially in architectural projects. Since 2016, it has started to be used more effectively by the project management team. Nowadays, it is applied to project development and compatibility, construction site implementation process, and construction work planning. Both 4D and 5D BIM are in the maturing stage.

Company Beta started its BIM implementation process in 2011, initially using it to transform 2D into 3D projects. Since then, they have finished 11 virtual construction projects, aiming to implement BIM in the maintenance stage as a next step and integrate the work into a single virtual platform. The Lean philosophy was implemented in their construction sites approximately simultaneously, seeking to stabilize production with the implementation of short-term, lookahead, and long-term planning, the identification of activities that add value, and prototyping, among other uses of Lean in their sites.

Company Gamma has over 70 years of experience with industrial projects, infrastructure works, urban mobility, energy, oil, and gas construction projects. Since 2018, the company has started BIM implementation in all its projects related to the Engineering Department; however, it has worked with BIM for about ten years in case projects. The company has been working with Lean for ten years and has a "Lean Excellence System." Nowadays, this system is applicable throughout the company, aiming to structure projects to integrate 100% BIM and Lean.

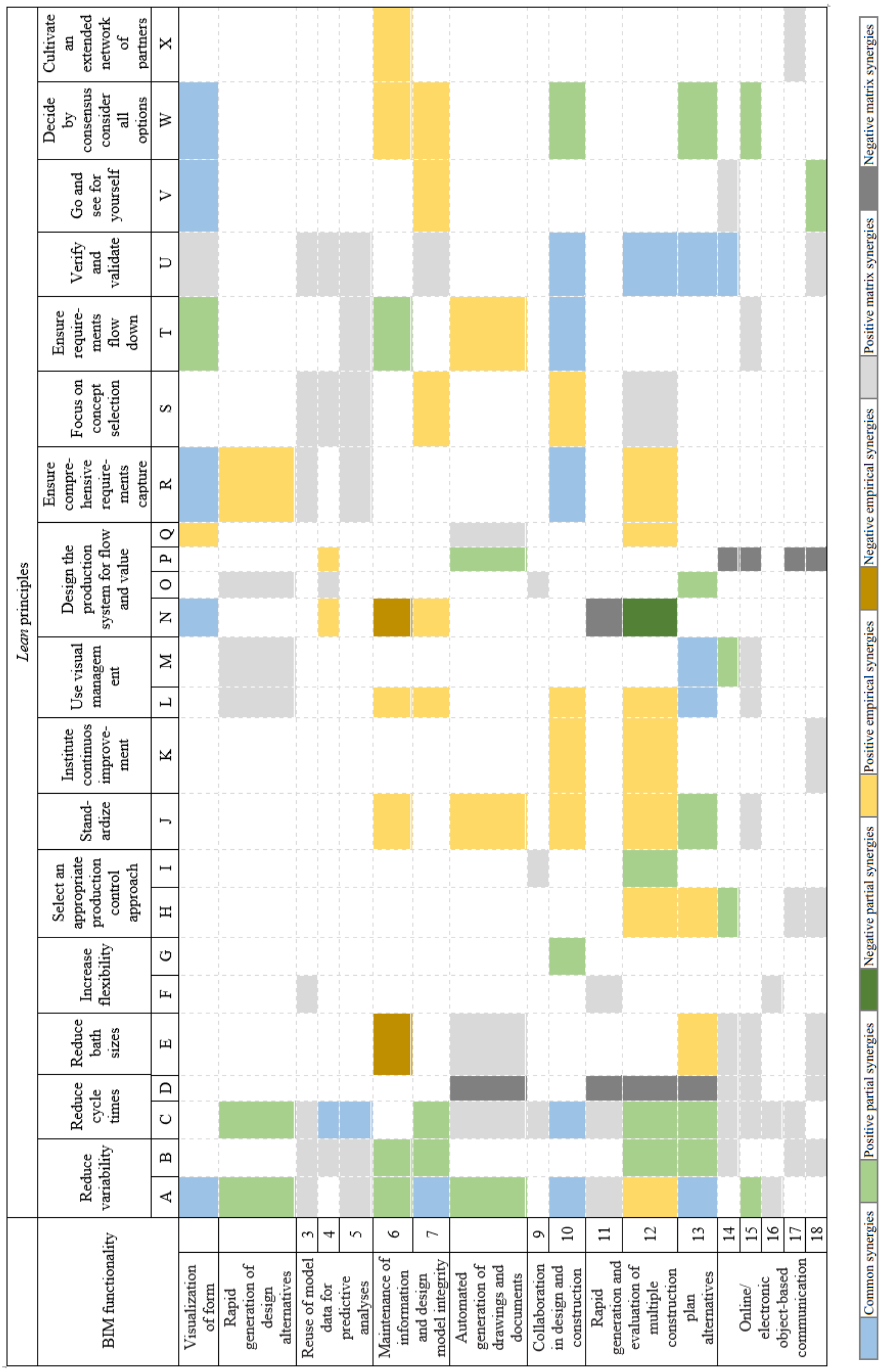

Figure 1: Companies' Practical Interaction Matrix for Lean Principles and BIM Functionalities

Sacks et al. (2010) presented an interaction matrix based on emerging evidence from research and practice. Figure 1 is a replica of the matrix presented by the authors, in which Lean principles are named "A to X" and BIM functionalities are numbered "01 to 18". In order to understand the terms better, the work by Sacks et al. (2010) should be consulted.

Next, each BIM functionality will be presented, and the synergies presented in Figure 1 will be explained. We will present the Lean principles associated with each BIM functionality and justify why we marked the synergy between them.

COMMON AND PARTIAL SYNERGIES

Visualization of form (1)

The 3D model makes possible a comprehensive and multidisciplinary visualization, helping to identify errors before they happen and ensuring a better quality **(A)**. The 3D model also simplifies **(N)** to present information in the product and construction process and help define execution order **(Q/R/T)**. As we can observe from the interview with Company Alpha: "In complex projects (...) we end up using (the model) as a way to better understand that project. The visualization allowed by the model also facilitates the Gemba walk **(V)** because now it is possible to visit the project and the construction site virtually".

BIM helps with decision-making process **(W)**, especially when many professionals are involved because it uses a single representation of information that everyone can access. According to the example given by Company Beta representative: "We involved designers of ambiance, landscaping, installations, and structures. When they start developing the preliminary study, BIM comes in, takes everyone's designs, and models them since the preliminary study. We can now visualize better how that product will be."

The processes simulation guarantees that planned will be executed **(U)**, as spoken by Company Gamma: "The "excellence" staff, for some doubts, used the model to see if the crane was going to hit some piece, if there was some interference. The *rigging* plans are much more assertive because they were actually made on the digital model."

Rapid generation of design alternatives (2)

Due to the rapid generation of several possible scenarios, the BIM model enables analysis and verification of which processes allow a shorter cycle time **(C)**, considering in each of these scenarios possible conflicts and complications to be defined, diminishing variability **(A)**. According to the example mentioned by Company Alpha representative: "It is a way of simulating construction site layout, rack positioning, work strategy, and crane positioning. We already use this approach for mapping primary and secondary trays."

The simulation allows greater process assertiveness due to visualization capabilities, ensuring that the customers' requirements are met; as Company Gamma representative said **(R)**: "We use it to see the coherence and consistency of our standards. If it is going to meet our needs, if it can quickly simulate if what we are going to standardize is going to meet customer's needs or not, should any changes arise along the way."

Reuse of model data for predictive analysis (4/5)

Using BIM models allows the exportation of information and documents automatically, with more assertiveness of model data and reducing the cycle time to obtain it **(C)**. By obtaining data from the model, construction planning becomes more accessible and more reliable **(N)**, as stated by the Company Beta representative: "We always had doubts regarding our construction execution layers, to get quantitative data. When we saw that the data extracted from the model was reliable **(P)** in comparison to manually extracted data, we saved time and evolved a lot when using BIM."

Maintenance of information and design model integrity (6/7)

Identifying incompatibilities and restrictions before execution **(T)** allows to remove them in advance **(A)**, resulting in reduced variability **(B)** and reduced cycle times **(C)**. As mentioned by Company Gamma: "Assuming that Lean has constancy and predictability, and this involves reducing variability, BIM comes in hand to assist in the ability to see, perceive what is a restriction, what is a problem, and what is an incompatibility."

By using parametric objects, model updates happen automatically **(N)**, allowing uniform detail representation **(J)** and construction methods **(L)**. As stated by Company Beta: "(...) We model facilities. We even know where the boxes are, the facilities, and their heights. In a kitchen, for instance, (…) we know that in the porcelain tiles, we will have the boxes at a given height, and we could improve a lot in the prototype so that after the prototype, we can replicate the standardization for the rest of the construction site."

A single database allows that the concept is well defined (**S**) since all stakeholders participate in the process and generates a virtual construction that can be visited off-site **(V)**, as mentioned by Company Gamma representative: "We realized that the collaboration of the tool **(W)** allows us to anticipate project problems that are dealt with immediately, with the collaboration of all involved **(X)**. That way, the lead time of the process is reduced **(C)**, besides avoiding revisions, unidentified errors as well as compatibility and interference issues **(A)**."

A negative impact identified during the interviews is that an over-detailed model can lead to more batches **(E)** due to the amount of information, which contradicts the ideal batch sizes for good management, hindering its use and diminishing simplification **(N)**.

Automated generation of drawing and documents (8)

Since it is a model formed by parametric objects, BIM allows the extraction of information and sets of coordinated drawings, diminishing variability **(A)** because any changes are automatically updated in the model, ensuring that the correct information is shared. As mentioned by the Company Gamma representative: "We have a standard spreadsheet that exchanges information with the library, that communicates with the budget. When the layout (the construction site) is defined, this spreadsheet is automatically completed and sent to the budget." **(P)**

It is possible to use BIM to generate automatic documentation of standardized parts, ensuring that the information is shared correctly **(T)**; as the Company Alpha representative said: "We takeout our documentation from BIM (framework and some accessories), door and countertop standardization."

Collaboration in design and construction (9/10)

Via the compatibility of design disciplines and collaboration amongst all designers, it is possible to identify what adds value to the customer and then execute the designs with quality **(A)**, reducing the variability of product and production. These characteristics allow fluid development without reworks and shorter cycle times **(C)**.

The opportunity to work with multipurpose teams **(G)** within the same data source might facilitate integrated decision-making, which allows better analysis, resulting in the best solutions **(R)**. According to Company Gamma: "BIM promotes optimization in engineering. We testes some market solutions, which nowadays involve the customer, our designers, our site project managers, our construction team, and our BIM team **(L)**, all in the same environment, working on the same model **(S)**. Everyone is working on the same database **(J)**, on the same information, defining the best solutions **(W)**. When we talk about the federated model, with all disciplines, everything is in the same place." **(T)**

BIM allows an analysis of the building before its construction due to the amount of information contained and how information is demonstrated. One possibility is the virtual Gemba **(U)**, which consists of verifying the whole building with professionals from different areas to collect data, identify possible problems, and resolve them during the design phase. As mentioned by the Company Alpha representative: "In Virtual Gemba, we involved the project manager, the project supervisors, the project designers, and the budget team. It is an event between the company and our suppliers." **(G/K/T)**

Robust models allow for more assertive constructions because they enable analyzing data visually before construction, generating better processes **(K)**, as exemplified by Company Alpha representative: "We made a comparison of how much we saved, how many incompatibilities there were, and the estimated savings in the construction budget. We found problems that would cost a loss of around 800 thousand Brazilian Reais, resulting in a three percent saving on the budget. Four significant incompatibilities that we found and the investment made on BIM represented 80 thousand Brazilian Reais, so there is nothing that compares to using BIM."

Rapid generation and evaluation of multiple construction plan alternatives (11/12/13)

By simulating construction from the BIM model linked to the schedule, it is possible to control the works, allowing a better understanding **(R)**, in addition to visualizing construction better in time, contributing to the identification of problems more quickly, correcting them as soon as possible **(Q)**. According to the example given by Company Beta representative: "So, we start with BIM, then we move to our line of balance, then to our 4D, and finally we take it to the construction site so that we can pull it (work) there **(H)**. And then, obviously, what goes into planning should reflect in the construction site."

BIM allows the visualization of construction processes **(L)** and, consequently, clash identification, either in space or time, enabling their anticipation, thus improving process efficiency **(K)**. As an example given by Company Gamma representative: "If you used to do it without BIM, you would have much re-planning to do, because you did not could see the whole picture. Now, with BIM, you can see everything, involve people visually, and have much less re-planning to do **(A/N)**."

Due to the better visualization of construction, BIM makes it possible that clashes are found in space and time **(U)**, allowing cycle time reduction **(C)**, improving project standardization **(J)**, and ensuring information flow between all professionals involved. As stated by Company Gamma: "Before BIM, we would take an operational procedure and the project and pin them to the wall so that our staff could see the procedure in their minds. And they started to have a perception of uncertainty regarding what the model was and continued to think that it was wasteful. If at this point in planning you can detail people's progress **(B)**, for instance, you can reduce cycle time **(C)**, because it is possible to see if there is overlapping work, which is part of the cycle time **(R)**."

The simulation process can indicate uneven work allocation, allowing a better assessment of work assignments and checking for peaks and valleys during the production process **(I)**. As mentioned by Company Gamma: "In our detailing stage, where we talk about pull planning, (…), you model and define which information level to be used when detailing and can use that information to level (production). If you do not use BIM and need to plan quickly, sometimes you will not have enough time, and might imagine that it is leveled. Using BIM, you have more flexibility and can generate these graphs faster to see if what you planned online is peaking or not."

It is possible to have a better perception regarding the size of work packages **(E)** due to the visualization offered by BIM. As mentioned by the Company Gamma representative: "We work with large projects, which means that we will not have repetitive structures. I cannot define a fixed batch for these projects. Usually, we go little by little, prioritizing flow to activities that are in parallel. We have already managed to identify restrictions on pre-defined batches through BIM."

It is possible to analyze processes that, in practice, would be challenging to test due to the various possibilities of simulating one-off events. As stated by Company Gamma: "In a dam project, for instance, BIM helps decide the construction methodology. You simulate the construction steps for the planned dam, and you realize there will come a time when the form will be so big that it is better to make it a sliding shape. These are solutions that we have applied numerous times, and at this point, we can be flexible **(L)**."

BIM facilitates complex detailing, allowing better process standardization **(J)**. The simulation of several disciplines within a single model, related to the experience obtained on-site, provides the possibility for lessons learned **(K)** that can be shared and used in future projects, thus generating continuous improvement. As pointed out by Company Gamma: "Usually, we waited until the end of the construction work to obtain the lessons learned and use them for future projects. Today, if we can simulate the model, we start to criticize our times, optimize things for the client, and provide them with a shorter schedule. So today, what we are using more in lessons learned are in the proposals."

A negative interaction was brought by Company Gamma: "BIM exposes a problem. You say: I'll do everything complete, detailed. (...) Sometimes, you spend more energy on the model to be able to make something that you won't even use **(N)**."

Online/electronic object-based communication (14/15/16/17/18)

Simulation of the process status enables visual management, facilitating the creation of a schedule with continuous activities, avoiding gaps during production, thus implementing a pulled flow **(H)**, allowing through online communication even off-site control **(M)**. With accessible information for all involved in the process, it is possible to identify problems and correct them before they happen **(A)**. According to Company Alpha: "BIM helps us guarantee the schedule, which already is pulled. It ensures this by allowing you to simulate, model, and visualize restrictions **(W)**." The same person stated: "With 4D you can visualize you should be, and where you are today (...). We can see what should be already finished, what we are executing right now, and what is about to start." **(V)**

EMPIRICAL SYNERGIES

Part of the empirical synergies is correlated with the Simulation of the Construction Process and 4D Visualization of Construction Schedules. The companies have been using such functionalities, and these interactions were not identified before by Sacks et al. (2010). These synergies show that interactions between Lean and BIM have increased over time, possibly due to BIM diffusion and the development of technologies and innovations in this field of knowledge. Another reason might be that Sacks et al. (2010) study used mostly theoretical references, while this study also used practical observations.

The Lean principles that had the most empirical synergies were visual management and standardization, related to the BIM functionality of conflict verification, visualization of multidisciplinary models, construction process simulation, single source of information, and automated generation of drawings and documents. Following this evidence, Bayhan et al. (2021) identified standardization, information accuracy, and continuous improvement as important production characteristics. The authors identified that clear communication and visualization, aided by Lean/BIM integration, enable more significant success in the construction processes.

MATRIX SYNERGIES

We can see a significant number of matrix synergies. Some synergies identified by Sacks et al. (2010) require aspects such as a high level of BIM and Lean maturity and their interaction, advanced technology, or supply chain integration. The interviewed companies did not achieve these aspects, which might explain this high number.

Also, some synergies are directly related to the product concept, which these companies rarely contemplate since they focus on the construction phase and not on the development of projects. In addition to synergies related to the reuse of data, it was identified, through the interviews, that none of them uses BIM models for performance analysis, such as acoustic, thermal, or energy analysis. Thus, no interaction of this profile was found. Another difference is the sample size for data collection. Other synergies could have been found from interviews with other construction companies.

DISCUSSION

Despite being companies of different sizes with different processes and implementation times for Lean Construction and BIM, the common synergies demonstrate that some of these interactions are supported in practice. It can demonstrate a common path traced by companies that decided to implement Lean Construction and BIM, which can be followed by companies that want to carry out this transformation.

The matrix shows that all synergies related to verification and validation were classified as common synergies. That can be explained by the multidisciplinary model, which helps with verifying interferences before execution, besides allowing a comparison of what was executed with what was planned from the 3D model visualization and construction simulation. In line with this finding, Fosse et al. (2016) state that visual management is the greatest benefit of BIM to Lean Construction, as it enables faster clarification and consensus thanks to a clearer flow of information.

Since 3D visualization is part of the BIM methodology, such advantages are perceived without further effort. The BIM model is used to anticipate problems and solve doubts that may arise in the construction site through visualization and multidisciplinarity (Bayhan et al., 2021), helping to reduce variability (Mollasalehi et al., 2017). From the matrix, we can see that BIM can contribute to applying this lean principle, being pointed out this way by the three companies.

Some reasons that explain the presence of partial synergies are the difference of BIM and Lean implementation maturity, construction type or construction system used by the companies, and each company's strategy. Most of the partial synergies were found in Company C, which can be explained because this company does not work with repetitive batches. So, it found more benefits in BIM in reducing cycle time and its production system since the company uses its features to have more assertiveness in batch size and better information management. Another characteristic is that Company C works sharing a single database, facilitating collaboration in various areas of BIM functionalities.

Given the found synergies, it is important to emphasize what differentiates BIM and Lean. One of the interviewees highlighted: "The more integration between Lean and BIM, the better. You can make BIM helps Lean a lot. However, I emphasize that the company's philosophy should be a management philosophy. Lean is a management philosophy. BIM is a work methodology that helps a lot when developing projects and construction sites. But you need to *breathe* Lean. BIM helps Lean." The interviewee also points out: "Lean does it all, and BIM helps you to visualize." and: "Lean has a greater importance degree in management terms than BIM, so as not to leave the two at the same level."

CONCLUSIONS

The research findings make it possible to verify how the synergies between Lean and BIM have been perceived in three Brazilian companies. From the interactions identified through the interviews with the companies, we could assemble a matrix similar to the original one to compare them. Through the comparative analysis, four classes were determined according to where the interactions were identified, and then each class was studied separately to understand them. Of the 146 results (positive and negative) indicated in Figure 1, 13.01% (19 interactions) were common synergies; 17.81% (26, one being negative) were partial synergies; 23.29% (34, two being negative) were empirical synergies, and 45.89% (67) were matrix synergies.

As we can observe from the results, most synergies presented by Sacks et al. (2010) were not identified in the interviews with the three companies, which some limitations might explain: a) Technology level and BIM and Lean implementation maturity of the companies; b) Some interactions may be occurring in the companies and were not observed during the interviews; c) A small number of construction companies were studies; d) Companies focused on construction/operation were interviewed, not considering companies that work with project development; e) the difference of more than ten years between the publication of Sacks et al. (2010) and this work.

The second most common classification was empirical synergies. Despite not being addressed in the original matrix by Sacks et al. (2010), companies have presented new Lean and BIM synergies, deserving a future theoretical discussion.

Through the matrix (Figure 1), we can confirm the result found by Dave et al. (2013). The lean principle that had the most interactions with BIM features was the reduction of variability followed by designing the production system for flow and value, enabling a better-designed product and thus reducing variability. Thus, it can be concluded that such aspects will contribute to a reduction in the overall construction time.

This work contributes to scientific knowledge by approaching the matrix developed in the seminal study by Sacks et al. (2010) with a practical view, a topic that had been previously addressed by other researchers, from a theoretical approach or with the realization of some comparative studies (theory x practice) of specific interactions. In addition to the scientific contributions, it collaborates with technical knowledge, indicating the most common Lean and BIM interactions to be implemented by companies, raising the possibility of creating a path to be followed in the future by companies.

Furthermore, empirical synergies can demonstrate that interactions between Lean and BIM have increased over time, possibly thanks to BIM diffusion and the development of technologies and innovations in this field of knowledge.

This exploratory study encourages new research, both qualitative and quantitative. We suggest, for future work, increasing the number and diversity of companies in order to ratify the original matrix constructed by Sacks et al. (2010) and facilitate the implementation of systemic interactions of Lean and BIM, thus contributing to the improvement of design and operations quality in civil construction.

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