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UNDERSTANDING THE RELATIONS BETWEEN BIM MATURITY MODELS AND LEAN PRINCIPLES

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ABSTRACT

The increasing adoption of BIM is requiring organizations to assess their BIM maturity level. For this assessment, several authors have proposed BIM maturity models to assess capabilities of organizations or projects. However, although previous researches have demonstrated positive synergies between Lean philosophy and BIM, it is not clear the role that Lean principles currently have in the assessment of BIM maturity.

This study aims at understanding the relation of 5 BIM maturity models with 16 Lean principles. The research shows that the principles related to flow process has the most interaction with the maturity components, where “Reduce Variability” is the principle with the highest number of interactions, followed by “Reduce cycle time” and “Design the production system for flow and value”. The results also showed that “Problem solving”, “Value generation process” and “Developing partners” are Lean principle clusters with low levels of interaction in the analyzed models. Future research should study the convenience of their incorporation in order to align BIM maturity improvement with Lean principles to enjoy the benefits of Lean and BIM synergies.

KEYWORDS

Lean construction, BIM, maturity models.

INTRODUCTION

One of the most important current approaches to address productivity problems in the construction industry is Building Information Modeling (BIM), with an increasing adoption rate in the last years. This high interest can be explained by BIM´s promise of improving the construction performance and efficiency (Azhar, 2011). Nevertheless, if BIM is not properly implemented, organizations may incur in additional costs or reductions in efficiency (Chu, Matthews, & Love, 2018).

One of the causes for these potential unwanted outcomes is stakeholders without the required capabilities and awareness for the BIM uses in the construction projects (Gu, Singh, Taylor, London & Brankovic, 2008). Thus, the assessment of BIM capabilities and the maturity of those capabilities is becoming essential not only for owners to select design and construction firms that may participate in their BIM projects, but also for any stakeholder to understand their situation applying BIM (Rojas et al., 2019) and thereby

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trace an action path to improve it. To assess these capabilities, academia and industry are looking at maturity models.

Maturity models can be defined as a sequence of stages that represents the knowledge and mastery in a determined area via the analysis of diverse criteria (Wendler, 2012). Its use relies on the assumption that levels are able to indicate the real capabilities of an organization and how the evolution of these capabilities should be done, bringing opportunities to improve and eliminate deficient capabilities. The evidence of the derived benefits in other industries led to BIM researchers to propose the use of these models (Chen, Dib, & F. Cox, 2014) in the construction industry at the people, organization and project levels.

On the other hand, another approach to address construction productivity problems is Lean Construction, which is a philosophy based on continuous improvement, waste reduction and value generation (Sacks, Koskela, Dave, & Owen, 2010). Different authors have studied the relation between BIM and Lean, identifying positive interactions in their combined use (Dubler, Messner, & Anumba, 2010; Hamdi & Leite, 2012; Mandujano, Alarcón, Kunz, & Mourgues, 2016; Sacks et al., 2010).

However, despite the evidence of these synergies, the literature that has analyzed and compared BIM Maturity Models (Dakhil, Alshawi, & Underwood, 2015; Giel & Issa, 2013; Wu, Xu, Mao, & Li, 2017) has not yet explored these interactions, leaving unclear how Lean principles relate to the BIM maturity assessment process. Therefore, the objective of this research is to understand the relations between existing BIM maturity models and Lean principles. Thus, this study assessed the connections between 16 Lean principles and each BIM area throughout its maturity stages for five BIM maturity models.

LITERATURE REVIEW

MATURITY MODELS

The concept of process maturity and its measurement started in 1979 with the development of Crosby's quality management maturity grid. This grid is composed of six measurement categories where each of them has five maturity stages (Paulk, 2009). The grid refers to an arrangement of categories or areas in one direction, and maturity stages in the other direction. Since then, several industries or knowledge areas have developed their own maturity models, such as software development, construction industry, public management, medical management, business intelligence, and knowledge management (Wendler, 2012). These maturity assessment methods have demonstrated that an increase in the maturity of a process can reduce its variability and improve its performance (Succar, 2014).

Maturity models establish defined areas and characteristics for which the objects of evaluation must demonstrate their maturity (Chen et al., 2014). These models define a sequence of stages (or maturity levels) where the bottom stage can represent having a few of the total capability studied and the highest stage represents the full maturity in the capability (Becker, Knackstedt, & Pöppelbuß, 2009).

These models have descriptive, prescriptive and comparative purposes. The descriptive purpose considers the maturity models as an assessment tool, defining evaluation criteria and giving a diagnostic about the current status. The prescriptive purpose aims at giving guidelines and a route for future actions, and finally, the comparative purpose uses the models to create benchmarks among the assessed elements (Pöppelbuß, Niehaves, Simons, & Becker, 2011).

In the BIM domain, the National Institute of Building Science (NIBS) (2007) developed one of the first maturity models. This model consists of a matrix where the rows represent the levels and the columns the capabilities that will be measured. In total, it defined 11 capabilities and 10 maturity stages. Other authors also have proposed BIM maturity models that look for a new purpose and try to fulfill the gaps left by the previous models (Succar, 2009; Sebastian & van Berlo, 2010; CICR, 2013; Kam, Song, & Senaratna, 2017; Indiana University, 2015).

Several studies (Giel and Issa, 2013; Dahkhil et al., 2015; Wu et al., 2017) have reviewed and compared some of the BIM maturity models for different purposes but none of these studies have related the models with the Lean principles.

BIM AND LEAN SYNERGIES

Recent literature has an increasing interest in BIM and Lean relations, demonstrating their capability to reduce the waste generated in the construction process (Dubler et al., 2010), and to improve the construction performance, suggesting further research in this area (Dave, Koskela, Kiviniemi, Owen, & Tzortzopoulos, 2013; Mollasalehi, Fleming, Talebi, & Underwood, 2016).

Sacks et al (2010) is one of the most exhaustive studies related to interactions between Lean and BIM. They established an interaction matrix that identified 56 interactions related to 24 Lean principles and 18 BIM functionalities, where 52 of those interactions represent a positive synergy. Most of these interactions were documented through evidence from practice or previous research. Mandujano et al. (2016) complemented this study by extending the concept of BIM to VDC (Virtual Design and Construction), finding 224 interactions, where 219 represent a positive synergy.

Through a case study, Hamdi and Leite (2012) studied BIM and Lean interactions from two separate perspectives: from the Sacks et al's Interaction Matrix and from the NBIMS's maturity model. In the first perspective, they studied 3 positive synergies, obtaining improvement areas in the organization. In the second one, they evaluated the BIM maturity through the model proposed by NBIMS and identified the involved Lean principle and the Lean practice that can help to improve the maturity for each area, such as 5s process, increase visualization of process or fail safe for quality and safety. Finally, notwithstanding they did not make a full use of the Interaction matrix, they found interconnections in how the Lean principles can enhance BIM maturity.

Although the above references and other literature has shown a strong evidence related to the synergies between BIM and Lean, BIM maturity models have not intentionally considered the relation between BIM competencies and Lean principles. The literature shows only two exceptions to this. The first, is the maturity model developed by the University of Salford that aims to support the joint implementation of BIM and Lean (Dave et al., 2013). However, there is limited public information related to the assessment mechanism. The second is the IDEAL maturity model that attempts to integrate BIM and Lean in the same model. However, there is information only about the definition of the maturity stages but no about of the capabilities assessed by the instrument (Mollasalehi, Aboumoemen, Rathnayake, Fleming, & Underwood, 2018).

Based on the gaps observed from the literature review, this study aims at understanding the relation between BIM maturity models and Lean principles. This understanding will contribute to choose between or modify existing maturity models. The use of proper maturity models will allow organizations to exploit synergies between BIM and Lean.

RESEARCH METHODOLOGY

Figure 1 describes the main steps of the research methodology.

Figure 1: Main steps of the research methdology

Through an integrative literature review, the authors selected BIM maturity models with available description for both the assessed areas and their maturity stages, as the lack of the description of the stages would have introduced biases in the assessment process. To identify the relations between the BIM maturity models and Lean principles, the present research used the 16 Lean principles as defined by Sacks et al. (2010) as the analytical framework, since this list was formally compiled specifically to analyse interconnections between Lean and BIM. Table 1 shows the organization of these principles.

Table 1: Lean principles and their organization (Sacks et al., 2010)

Areas	Principles	
Flow process	A. Reduce variability	F. Standardize
	B. Reduce cycle times	G. Institute continuous improvement
	C. Reduce batch size	H. Use visual management
	D. Increase flexibility	I. Design the production system for flow and value
	E. Select an appropriate control approach	
Value generation process	J. Ensure comprehensive requirements capture	L. Ensure requirement flow down
	K. Focus on concept selection	M. Verify and validate
Problem solving	N. Go and see yourself	O. Decide by consensus, consider all options
Developing partners	P .Cultivate and extend network of partners	

The analysis described in this paper assessed the connections between these Lean principles and each BIM area throughout its maturity stages for all the selected BIM maturity models. This assessment specifies whether this relation is present in all the maturity stages (F, full), only in some of the stages (P, partial), or in none of them (I, inexistent). Besides, the F and P relations specify if the relation represents a positive integration of the principle (+) (higher maturity aligns with the principle), a negative integration (-), or there is an inconsistency (+-) throughout the different maturity stages.

RESULTS AND DISCUSSION

In a first stage, the authors identified 13 maturity models with literature that support them (Table 2). Nine of these models had available information about the description for each area assessed, but only 5 of them had publicly available descriptions of each maturity stage. These 5 models are the Capability Maturity Model (CMM), BIM Maturity Matrix at granularity level 1 (BIM MM), Organizational BIM Assessment Profile (Org. BIM AP), Multifunctional BIM Maturity Model (Mult. BIM MM) and the Arup Maturity Measure (Arup MM).

Table 2: Identified BIM Maturity Models (highlighted models were used in the study)

Maturity Model (Source)	Assessment Focus	Capabilities Description	Detailed Maturity Stages Description
Capability Maturity Model (CMM) (NIBS, 2007)	**Projects**	**Yes**	**Yes**
BIM Maturity Matrix (BIM Excellence, 2016)	**Organizations, project teams and markets**	**Yes**	**Yes**
BIM Proficiency Matrix (Indiana University, 2015)	Organizations	No	No
Characterization Framework (Gao, 2011)	Projects	No	No
BIM Quickscan (Van Berlo & Hendriks, 2012)	Organizations	No	No
Organizational BIM Assessment Profile (CICR, 2013)	**Organizations**	**Yes**	**Yes**
Lean/BIM Maturity Model (Dave et al., 2013)	Projects	Yes	No
VDC Scorecard (Kam, Song, & Senaratna, 2017)	Projects	Yes	No
BIM Cloud Score (Du, Liu, & Issa, 2014)	Organizations	Yes	No
BIMCAT (Giel & Issa, 2015)	Organizations	No	No
Arup Maturity Measure (Arup, 2015)	**Projects**	**Yes**	**Yes**
Multifunctional BIM Maturity Model (Liang et al., 2016)	**Projects, companies and industry**	**Yes**	**Yes**
BIM Maturity Tool (Siebelink, Voordijk, & Adriaanse, 2018)	Organizations	Yes	No

The study of the selected models shows no agreement regarding the number of capabilities to incorporate. A characteristic of some models is the arrangement of capabilities into fields. For example, the BIM MM incorporates the technology, process and policy fields; and in addition, the user must choose an area according to the BIM capability stage (object-based modeling, modeling-based collaboration or network-based integration), and other for the BIM organizational scale (Organizations, project teams or markets) that is assessing. Additionally, the Org. BIM AP integrates BIM uses, process, information, infrastructure and personnel fields, and the Mult. BIM MM does it with technology, process and protocol fields, whereas the other two selected models do not define fields for their assessed areas.

For analysis purposes, the present research considered the BIM MM as a whole of 16 areas, notwithstanding that at the assessment moment the assessors must select one BIM capability stage and one BIM organizational scale according to who is been measured. This decision is based on the importance of obtaining the best understanding about how maturity models involved the Lean principles throughout itself.

Another special case exists with the Arup MM. This model presents 11 areas that must be assessed once for the whole project and 11 other areas for each discipline of the project (mechanical, structural, electrical, etc.). The latter 11 areas are related to some of the BIM uses and are the same for each discipline; therefore, this research considers these capabilities only once. Additionally, the public documentation about the Arup MM did not provide definitions for the whole sequence of stages in some of the areas, but in order to have a more comprehensive study, the authors included these areas under the assumption that the maturity sequences are properly defined with fewer stages.

To exemplify the assessment rationale, the following discussion describes the assessment for the "Data Richness" area in the CMM instrument, which maturity stages (MS) are shown in Table 3 (parts a and b). The definition of stage 1 does not allow determining if there is a connection with the Lean principles because it just refers to basic data, reason that eliminates the possibilities to find an F type connection. The following stages include the evolution of the data amount and its association with information, becoming authoritative, until achieving Knowledge management system, which will help to "Reduce variability" and "Reduce cycle times" (Lean principles A and B, respectively).

Table 3a: CMM Data Richness, adapted capability (NIBS, 2007)

MS	1	2	3	4	5
Data Richness	Basic Core Data	Expanded Data Set	Enhanced Data Set	Data Plus Some Information	Data Plus Expanded Information

Table 3b: CMM Data Richness, adapted capability (NIBS, 2007)

MS	6	7	8	9	10
Data Richness	Data w/Limited Authoritative Information	Data w/ Mostly Authoritative Information	Completely Authoritative Information	Limited Knowledge Management	Full Knowledge Management

The matching with these principles can be understood with Sacks et al. (2010) definitions and examples of the principles. Principle A is achieved because the authoritative information will reduce the variability in the final product. On the other hand, principle B will occur because the Knowledge will reduce the task time due to the proper knowledge transfer that requires information, and thus, it will reduce the construction total duration. For principles C to E, G to L, and N to P, it is not possible to determine whether that principle will effectively be in any of the maturity stages. The F principle, Standardize, leaves more space for interpretation, as, according to Sacks et al, (2010), this principle refers to the standardization of work, which is not possible to stablish according to the maturity sequence because it refers to what the information is and not how is it used. Sacks et al. (2010) explain that the "Verify and validate" (M) principle implies that all products should be verified against the customer requirements and specifications. Thus, having authoritative information without checking the customer requirements goes against the principle (P- interaction).

In total, the 5 selected models provided 90 BIM measurement areas where the 16 Lean principles aforementioned were assessed. The basis for these assessments was the explicit or implicit relations declared in the maturity stages definitions, which – in several occasions – were supported by BIM-Lean interactions found in the literature (Alarcón, Mandujano, & Mourgues, 2013; Sacks et al., 2010). The research studied 1440 possible connections (16 Lean principles throughout the 90 BIM measurement areas), finding 291

P+, 20 F+, 7 P+- and 1 P-. The research did not find F+- or F- connections. The principles that represent P+- interactions are Reduce cycle times (B), Standardize (F), Reduce variability (A), Increase flexibility (D), and Ensure comprehensive requirements capture (J), as Table 4 shows.

Table 4: P+- interactions breakdown

Principle	Area	Maturity Model
B. Reduce Cycle Times	Roles or disciplines	CMM
	Operational uses	Org. BIM AP
F. Standardize	Graphical Info	CMM
	Data Exchange	Mult. BIM MM
A. Reduce Variability	Roles or disciplines	CMM
D. Increase flexibility	Organizational Hierarchy	Org. BIM AP
J. Ensure comprehensive requirements capture	Project uses	Org. BIM AP

This table shows that only one area presents 2 P+- interactions, the Roles or disciplines area in the CMM. This interaction occurs because of the inconsistency in the maturity progression, which shows a variation throughout the stages in if BIM fully or partially supports the people's job and if they need to go to other products to accomplish their job, creating variability in the cycle time and in the products that the organizations can make. Despite the fact that some areas of the studied models present inconsistencies with some Lean principles, in other areas, they have positive interactions with them. This situation can lead to difficulties at the time of improving Lean and BIM maturities in the organization but does not mean the incompatibility between them.

Regarding the negative interactions, the only principle that represents a P- interaction is Verify and validate (M) principle, in the CMM. The difference between the number of positive versus negatives interactions suggests that BIM and Lean go beyond the previous positive synergies detected in the literature. In addition, they have connections in the capabilities development, meaning that as BIM capabilities grow, the interactions with Lean principles may grow as well. The much more numerous presences of P+ connections compared with the F+ connections are due in part to the way that several models define the first maturity stage. Their first stage considers no or little development of the BIM measured areas, which usually conveys a lack of relation with the Lean principles. Considering the low presence of F+ connections in contrast with the P+, this study combined both as positive interactions, and proposed these metrics to analyze them.

$$Principle\ density_x = \frac{N^{o}\ of\ found\ positive\ connections\ for\ principle\ x\ considering\ all\ models}{N^{o}\ of\ possible\ connections\ for\ principle\ x\ considering\ all\ models}$$

$$Model\ density_y = \frac{N^{o}\ of\ all\ found\ positive\ connections\ in\ model\ y}{N^{o}\ of\ possible\ connections\ in\ model\ y}$$

$$Specific\ density_{xy} = \frac{N^{o}\ of\ found\ positive\ connections\ for\ principle\ x\ in\ model\ y}{N^{o}\ of\ possible\ connections\ for\ principle\ x\ in\ model\ y}$$

Figures 2 and 3 depict the specific versus the model densities, and the specific versus the principle densities, respectively. The average principle density is 0.22. However, this metric has a standard deviation of 0.18, representing a significant difference between the connections that a Lean principle has with the BIM maturity models. Thus, to have a better understanding of the detected interactions, the authors clustered the principles according to their density, using the k-means method (Jain, 2010). Table 5 shows the final clusters and their associated principles.

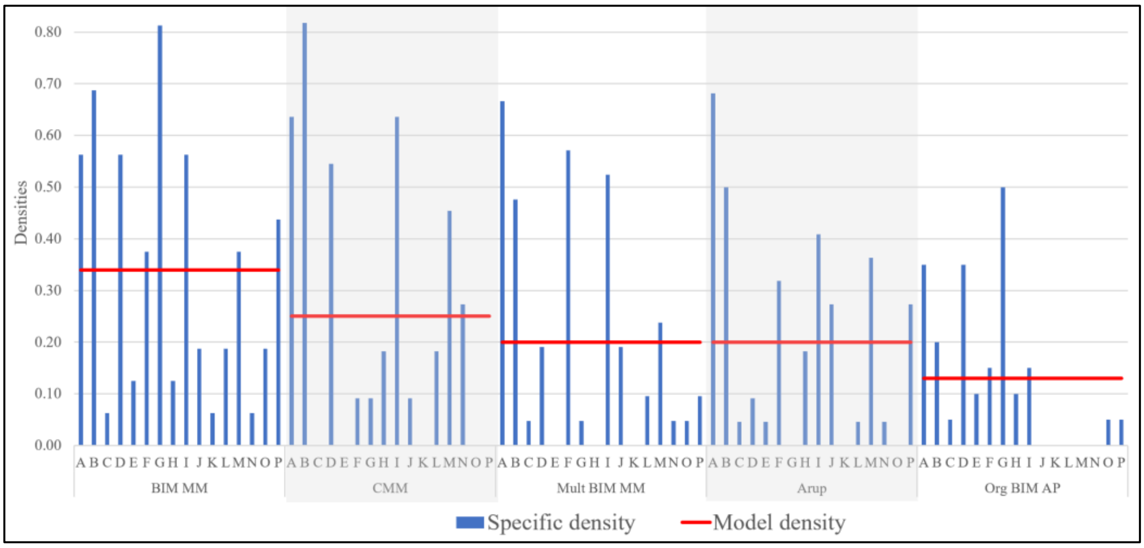

Figure 2: Specific density vs model density

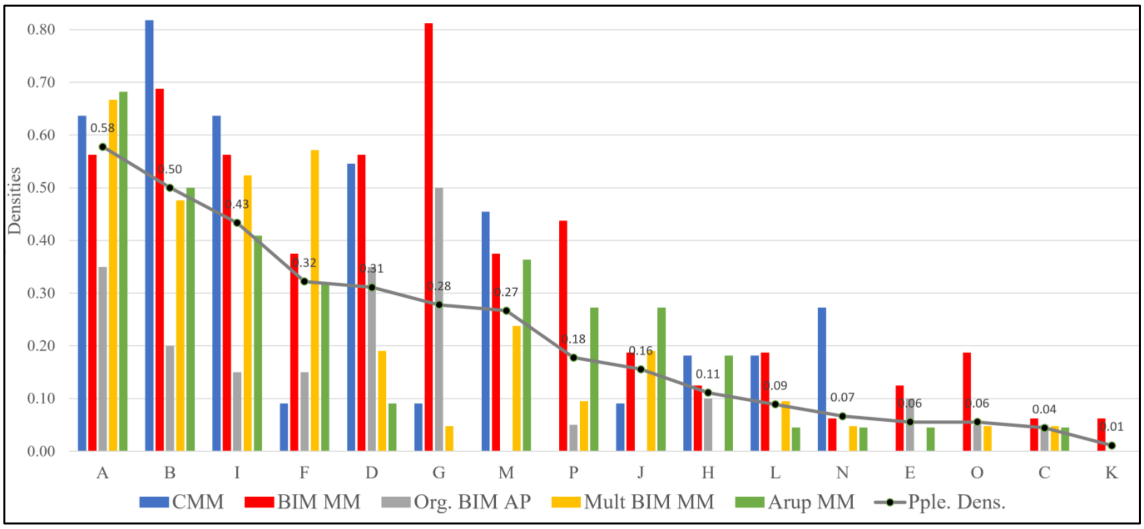

Figure 3: Specific density vs principle density

The results show that the strongest relationship is centered in the flow process principles, which implies that the improvement of their workflows may lead to higher maturities of organizations. The cluster of low principle density includes principles of the four areas. The principles with fewest interactions with the studied models are Focus on concept selection (K) and Reduce batch size (C), with densities of 0.01 and 0.04 respectively.

Analyzing by model density, the BIM MM presents the highest density, obtaining a value of 0.34 and being the only model that interacts with all the Lean principles. Also, the five models present high variability in the specific density, and all of them have a few principles with high densities, although these principles vary between the models.

Table 5: Principle clusters and their principles

Cluster	Density centroid	Principle	Principle area
High Principle Density	0.50	Reduce variability (A)	Flow process
		Reduce cycle times (B)	Flow process
		Design the production system for flow and value (I)	Flow process
Medium Principle Density	0.29	Increase flexibility (D)	Flow process
		Standardize (F)	Flow process
		Institute continuous improvement (G)	Flow process
		Verify and validate (M)	Value gen. process
Low Principle Density	0.09	Reduce batch size (C)	Flow process
		Select an appropriate control approach (E)	Flow process
		Use visual management (H)	Flow process
		Ensure comprehensive requirements capture (J)	Value gen. process
		Focus on concept selection (K)	Value gen. process
		Ensure requirement flow down (L)	Value gen. process
		Go and see yourself (N)	Problem solving
		Decide by consensus, consider all options (O)	Problem solving
		Cultivate an extended network of partners (P)	Developing partners

The use of the model density as a measure is useful to avoid biases that can be generated by the difference of the number of maturity areas of the models, and the consequent possible connections with the lean principles, allowing a normalized comparison among them. For example, the CMM present 44 connections with the Lean principles out of 176 possible connections. In contrast, the Arup MM have 72 connections out of 356 possible ones. Thus, looking only to the actual connections may lead to wrong conclusions as CMM has a higher model density than the Arup MM.

Regarding the models that have no connections with some principles, 4 of them do not include the Verify and Validate (M) principle, and 2 do not include Select an appropriate production control approach (E). The BIM Maturity Matrix is the only model that has specific densities for all 16 Lean principles.

CONCLUSIONS

Despite the evidence provided by previous research regarding the strong BIM and Lean synergies, BIM maturity models are not explicitly considering Lean principles in their assessment process and, therefore, it is not clear how much these synergies could be implicitly being considered when assessing BIM maturity. In the present study, it is possible to confirm the existence of these relations, but also that the magnitude of these interactions depends clearly on the characteristics of the maturity model. Moreover, findings exposed in the present article can help to decide what maturity model is the most suitable according to the Lean requirements that the organization or project has.

Even though none of the studied models explicitly express the aim to include lean considerations throughout its maturity stages, all of them present implicit connections with several principles. These results strengthen the evidence of BIM and lean synergies and suggest new approaches to exploit these synergies.

The studied models with focus on organizations present areas to measure management aspects, such as BIM champion, management support, or leadership, which may not have a direct relation with Lean nor express a BIM functionality. However, these could become relevant at the time to define who is in charge and solves problems, opening spaces to deeper integration with lean, and enhance the connections with principles from the Problem solving area, which is not being included in some models. Furthermore, the results do not show a difference in how a model incorporates the lean principles regarding the maturity assessment focus (i.e., projects or organizations).

Whereas a higher integration of lean principles seems to be a positive characteristic of a maturity model, the authors believe that a measurement area should not necessarily include all the principles, nor a principle must be connected with all the maturity areas. On the contrary, a parceled-out principle inclusion may create more and better synergies, i.e., improve the project results by their combined use, since a simpler maturity sequence will produce clearer improvement strategies.

Based on the obtained results, the BIM Maturity Matrix has the strongest connection with lean principles, as it presents the highest model density (0.34), and interacts with all the Lean principles. In contrast, the Org. BIM AP has the weakest connection due to its model density (0.13) and the fact that it does not include 5 of the 16 studied lean principles.

The flow process principles are the ones with higher densities, especially the principles Reduce variability (A) and Reduce cycle time (B). These two principles naturally emerge as the most related to the five studied models, as well both principles can be considered with a direct relationship with the BIM promise of improving the construction industry. However, the studied models are weak in the inclusion of value generation process and problem-solving principles. These areas may improve the performance predictability and actually do not have a strong presence in the studied maturity assessment methods. Future BIM maturity models may consider the Lean philosophy from the beginning of their development and take advantage of the BIM and Lean synergies.

Further research is necessary to understand the relation between BIM and Lean maturity, and the companies´ BIM performance in order to better inform decisions about where companies should put their scarce resources aimed at improving their maturity.

The main limitations of the present study are the lack of publicly available information that did not allow to include other maturity models, and the absence of first-hand case studies to add practical considerations in the assessment of the connections between the maturity of the BIM competency sets and the lean principles. Future research could extend these contributions by assessing the relation between BIM and Lean maturities and key performance indicators associated with BIM processes.

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