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THE COMPATIBILITY OF EXISTING BIM MATURITY MODELS WITH LEAN CONSTRUCTION AND INTEGRATED PROJECT DELIVERY

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SUMMARY: *Building Information Modeling (BIM), Integrated Project Delivery (IPD), and Lean Construction (LC) are individually gaining increasing penetration in the Architecture, Engineering, and Construction (AEC) industry. Existing maturity models for each of these areas allow organisations to assess their current capability and guide their future pathways to increasing competence. There are significant mutual dependencies among these approaches; hence it would be useful for organisations to understand how to apply them to maximise the benefits across all three initiatives. An integrated BIM-IPD-LC (BIL) maturity model (MM) would break the silos among the initiatives by supporting this synergy. However, there is no comprehensive study on integrated organisational BIL maturity model design and development.*

This article presents the analysis of BIM maturity models as the starting point of research toward BIL MM development. BIM MMs are more widely cited and used within the construction industry compared to MMs for LC and IPD. This study uses the compatibility of BIM with IPD and LC in the context of MMs to identify how these three concepts can be synchronised. Comparative analysis is conducted using ten accessible, free, research-based, and frequently cited BIM MMs.They were then compared with a number of existing LC and IPD MMs. The results show that VDC Scorecard and BIM2FR are the most compatible BIM MMs with LC, and both the BIM Maturity Matrix and the VDC Scorecard closely correlate with the IPD characteristics compared with other BIM MMs. The findings of this study can be used as a basis for establishing the structure of a future integrated BIL maturity model.

KEYWORDS: *Building Information Modeling, Lean Construction, Integrated Project Delivery, Maturity Model*

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1. INTRODUCTION

Building Information Modeling (BIM) has been a significant enabler of the construction industry's transition from a fragmented to an integrated and value-adding sector. BIM is one of the most promising concepts in the construction industry. It reduces the negative effect of complex information flows among the many participants' involvement in the digitalisation of construction processes (Eastman et al. 2011).

BIM supports the recent construction industry concepts such as Lean Construction (LC) and Integrated Project Delivery (IPD) (Succar 2010; Sacks et al. 2010; AndÚJar-Montoya et al. 2019). The inherent characteristics of BIM aid in the fulfilment of LC principles by adding greater value to the various types of customers and reducing the various kinds of waste in the construction process (Dave et al., 2013; Tauriainen et al. 2016; Nascimento et al., 2018; Mahmood and Abrishami 2020; Evans et al. 2021). The advantages of BIM adoption in IPD projects have also been identified by several researchers (AIA 2007; Dave et al. 2013; Fakhimi et al. 2016; Nascimento et al. 2018; Salim and Mahjoob 2020). These advantages include the production of digital and visual architectural, construction, and as-built models; integrated information flow throughout the project life cycle; virtual construction scheme improvement; and increased automation (Zhang and Li 2014).

Despite the recognition of the interdependency of all three methodologies, BIM has gained considerable acceptance and adoption in the building industry in isolation. With the increased adoption of BIM, numerous BIM Maturity Models (MMs) have been developed to support the improved design and measure enterprise transformation strategies toward fully mature BIM implementation (Perkins et al., 2010; Langston and Ghanbaripour, 2016). Reliable BIM MMs have enabled different parties in construction projects to evaluate their strengths and weaknesses (Chen et al., 2014). BIM MMs, in particular, can contribute to BIM diffusion by providing a roadmap for policymakers and top management in businesses at both the macro and micro levels (Liang, 2016b). "A BIM-MM is introduced as the analytical framework to determine how BIM is implemented across projects" (Arup, 2014). While most of these MMs do not explicitly consider LC and IPD in their assessment scope, they do incorporate some relevant features. However, organisations interested in evaluating their performance in BIM, LC, and IPD have limited options for adopting these models collaboratively. Understanding the extent to which existing BIM MMs comply with LC and IPD requirements can aid in defining the characteristics of future BIM-LC-IPD MMs.

While recognised compatible BIM MMs with LC and IPDcannot be directly used for the performance measurement of the BIL synergy, they can help structure and organise the road maps for potential BIL implementation. As a result, this study seeks to determine the most operationally and culturally compatible BIM MMs with LC, as well as the degree to which MMs adhere to IPD principles.

2. METHODOLOGY

To conduct this study in the first stage, a set of selection criteria was identified based on the literature. As there is a wide range of BIM MMS, this paper focused only on those that were capable of overcoming industry adoption barriers and the remainder were excluded from the study.

The second stage involved comparing the level of compatibility of the nominated BIM MMs to two widely recognised and cited Lean Construction frameworks in the literature: 1) BIM-Lean Interaction Matrix Sacks et al. (2010) and 2). Lean Construction Maturity Model (LCMM) (Nesensohn, 2014). While both models define the characteristics of Lean construction, they approach Lean in quite different ways. According to Sacks et al. (2010), the BIM-Lean Interaction Matrix combines BIM functionality and lean concepts, creates theoretical links between them, and identifies constructive interactions during implementation. Indeed, it proposes a matrix that illustrates the operational relationship between BIM and LC. LCMM, however, is a MM aims to structure and assess the LC attributes from the organisational culture point of view. Each Lean attribute in LCMM is defined in the model for better clarification for the assessor about Lean aspects. Furthermore, each attribute in LCMM has a number of sub-attributes; as a result, a colour coding method was used to determine how many of them can be addressed by the chosen BIM MMs. Finally, the selected BIM MMs are compared to the American Institute of Architects' IPD principles (AIA 2007).

2.1 BIM Maturity Models - selection criteria

To study the BIM MMs as a starting point, a representative sample of MMs should be considered using appropriate selection criteria. The selection criteria can help identify the BIM MMs with the highest industry adoption. As a result, this study focuses on models capable of overcoming industry adoption barriers. According to Azzouz (2016), the significant barriers to the implementation of BIM MMs are a lack of support and guidelines from the model publisher, shortage of case studies; fees and unavailability of free models; and lack of clarity of variables in the models. To address these issues and respond to the shortcomings of the BIM MMs, the representative sample of BIM MMs in this paper met the following principles as the most responsive models to the BIM maturity implementation barriers introduced by Azzouz (2016):

- validated models through case studies,
- free and accessible models for obtaining the models' attributes,
- models with a robust research background and a clear description of the MMs' implementation methodology and definitions,
- highly-cited and recognised models in the literature (Table 1).

Table 1: Cited BIM maturity models

Articles	**NBIMS CMM**	**IU BIM Proficiency Matrix**	**BIM Maturity Matrix**	**BIM Quick Scan**	**Characterisation Framework**	**Organisational BIM Assessment Profile**	**VDC Scorecard**	**Owners BIMCAT**	**ARUP BIM Maturity Model**	**BIM Wedge**	**BIM Practical Implementation Model**	**Roadmap for BIM Implementation**	**Vico BIM Scorecard**	**BIM Multifunctional Maturity Model**	**Goal-Driven method for evaluation of BIM**	**BIM Level 2 BRE certification**	**TOPC evaluation criteria**	**CPIx BIM Assessment Profile**	**BIM Cloud Score**	**BIM Measurement Model**
(Kam et al., 2013)	●	●	●	●	●		●													●
(Liang et al., 2016)	●	●	●	●		●	●			●	●	●								●
(W. Wu et al. 2018)	●	●	●	●	●	●	●	●											●	●
(Siebelink et al., 2018)	●		●	●		●				●										●
(Lu et al., 2018)	●	●	●	●			●							●						●
(Yilmaz et al., 2019)	●	●	●	●		●	●						●	●						●
(Joblot et al., 2019)	●		●			●	●		●				●	●						●

The BIM MMs were analysed and scored based on these principles, and the results are summarised in Table 2. For each model, the selection criterion cell is marked with a bold dot if the evidence is available in the literature or on the maturity models website (Table 2). Models with scores below two were excluded from the study since they did not provide enough information for the model analysis.

TOPC evaluation criteria, BIM Level 2 BRE certification, and CPIx BIM Assessment Profile were omitted since they are fee-based models, and their attributes could not be accessed. The Vico scorecard is a BIM MM that is available online; however, it does not address the other selection criteria adopted by this study. For instance, there is no supporting document to reveal the tool development procedure or validation methodology. The model is not highly cited by the developers of other models, and there is little information about it in the literature. Furthermore, while the BIM Measurement Model met the paper selection criteria, it largely borrowed factors from existing maturity models (Lu et al., 2018). As a result, it has been excluded from the comparison study.

The remaining BIM MMs addressing at least two items of selection criteria are NBIM-CMM (National BIM Standard Project Committee 2007), IU BIM Proficiency Matrix (Indiana University 2009), BIM Maturity Matrix (Succar 2010), BIM Quick Scan (Sebastian and Berlo 2011), BIM Characterisation Framework (Gao 2011), BEW-Richard BIM Maturity Model, Organizational Assessment Profile (CIC 2011), VDC Scorecard (Kam et al. 2013), Owners BIM CAT (Giel and Issa 2014), Arup BIM-MM (2014), BIM Multifunctional Maturity Model (Liang 2016a), BIM Measurement Model (Siebelink et al. 2018), BIM-CAREM (Yilmaz et al. 2019b), and BIM2FR (Joblot et al. 2019). Following the selection procedure, the BIM MMs were analysed against the BIM-Lean interaction matrix (Sacks et al. 2010), the Lean Construction Maturity Model (Nesensohn 2014), and the IPD guidelines established by AIA (2007).

Table 2: selection criteria forBIM maturity models

	BIM Maturity Models																	
Selection Criteria	**BIM Quick Scan**	**Owners BIMCAT**	**Characterisation Framework**	**VDC Scorecard**	**NBIM-CMM**	**BIM Measurement Model**	**BIM-CAREM**	**BiM2FR**	**Arup BIM-MM**	**Goal-Driven method for evaluation of**	**BIM Maturity Matrix**	**Organisational Assessment Profile**	**Multifunctional BIM MM**	**IU BIM Proficiency Matrix**	**TOPC evaluation criteria**	**BIM Level 2 BRE certification**	**VICO BIM Score**	**CPIx BIM Assessment Profile**
Tested	●	●	●	●	●		●	●	●	●				●				
Highly Cited	●	●	●	●	●	●					●	●	●	●				
Research-based Tools	●	●	●	●		●	●	●		●	●		●		●	●		
Free-Available	●	●			●	●	●	●	●			●					●	
Total	4	4	3	3	3	3	3	3	2	2	2	2	2	2	1	1	1	0

The characteristics of the selected models are summarised in Table 3.

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Table 3. Reviewed BIM maturity models

BIM Maturity Models	Evaluation scope	Evaluation style	Origin	Hierarchy (Number of layers)	Year
NBIM-CMM	Project	Self-evaluation with an external reviewer for validation	US	One	2007
BEW-Richard	Organisation-Market	Self-evaluation with an external reviewer for validation	UK	One	2008
IU Proficiency Matrix	Organisation	Self-evaluation	US	Two	2009
BIM Maturity Matrix	Organisation	Four forms of evaluation according to granularity level	Australia	Two	2009
BIM Quick Scan	Organisation	External licensed assessor	The Netherlands	Two	2009
Characterisation Framework	Organisation	Self-evaluation	US	Three	2011
BIM Assessment Profile	Organisation	Self-evaluation	US	Two	2012
VDC Scorecard	Project	External assessor	US	Three	2012
Owners BIM CAT	Organisation	Self-evaluation	US	Three	2013
Arup BIM MM	Project- Discipline	Self-evaluation	UK	One each	2014
Multifunctional BIM Model	Projects, Companies, The construction industry	Self-evaluation	Hong Kong	Two	2016
BIM Maturity Tool	Discipline	Self-evaluation	The Netherlands	Two	2018
BIM CAREM	AEC/FM Processes	Self-evaluation	Turkey	Two	2018
BiM2FR	Organisation (Renovation Sector)	Self-evaluation	France	One	2019

3. LEAN ORIENTED BIM MATURITY MODELS

Lean Construction (LC) emerged as a management philosophy in response to the construction industry's inefficiency (Aslam et al., 2020). In its most basic form, lean means eliminating waste at every stage of a work process while adding value for the customer by completing value-adding functions as efficiently and quickly as possible (Tauriainen et al., 2016). The partnership between BIM and LC is currently a significant development in both professional and research fields (AndÚJar-Montoya et al., 2019). Al Hattab and Hamzeh (2018) argued that BIM could be considered LC tool since BIM functionalities have proven to reduce construction variability in construction projects and reduce rework (Mahmood and Abrishami 2020). Sacks et al. (2010) argue that using BIM and LC in collaboration with one another instead of just using them separately in projects could significantly improve the efficiency of the construction process.

However, the increasing implementation of BIM-Lean synergy leads to a demand for an appropriate combined maturity model. This integrated MM assists an organisation in identifying crucial elements affecting the implementation and enhancement of continuous BIM-LC synergy (Mollasalehi et al., 2018; Andújar-Montoya et al., 2020). Various maturity models have been developed to date in order to analyse individual BIM and Lean applications. However, the number of models capable of evaluating their combined use is still low. The review of the literature revealed that there are two BIM-LC maturity models available for assessing the performance of the joint synergy, "IDEAL" and "Integrated Lean and BIM Maturity Model". Mollasalehi et al. (2018) proposed a maturity model for projects that evaluates the effectiveness of BIM and LC's combination called IDEAL. Also, Lean and BIM implementation is measured against ten main criteria in the "Integrated Lean and BIM Maturity Model" developed by the University of Salford (Dave et al., 2013). However, the evaluation of BIM-LC in these two MMs is limited to a few minor aspects of each paradigm. For instance, BIM aspects do not go beyond information sharing and synchronised visualisation, and the model makes only little response to the process, technology, people, and policy. As a result, no comprehensive BIM-LC MM can be used in this study as a reference.

In this paper, BIM MMs are compared based on two academically well-recognised models: the "BIM-Lean Interaction Matrix" by Sacks et al. (2010) and the "Lean Construction Maturity Model (LCMM)" by Nesensohn (2014). The former demonstrates how BIM MMs can approach the BIM-Lean Interaction Matrix from a BIM functionality perspective in projects, and the latter demonstrates how BIM MMs are compatible with the highly recognised Lean maturity model, the LCMM, from the organisational culture perspective.

3.1 Comparison of BIM MMs based on BIM- Lean interaction matrix

The BIM-Lean interaction matrix developed by Sacks et al. (2010) was used as the basis to evaluate the LC capacity in the current BIM MMs. The "BIM-Lean Interaction Matrix" was used since it places great emphasis on BIM and Lean synergy. The matrix introduces eight BIM functionalities linked to 16 Lean principles. Fifty-six precise interactions have been identified from the matrix, where each BIM functionality addresses at least one Lean principle (Hamdi and Leite, 2012). This framework aids all the construction supply chain benefits from the synergy when planning Lean-BIM strategies; however, it can not be applied in an organisation as a MM. The BIM functionalities in the matrix are:

- *"visualisation of form;*
- *rapid generation of multiple design alternatives;*
- *use of model data for predictive analysis of building performance;*
- *maintaining the integrity of information and design models;*
- *automated generation of drawings and documents;*
- *collaboration in design and construction;*
- *rapid generation and evaluation of construction plan alternatives;*
- *online/electronic object-based communication;*
- *direct information transfer to support computer-controlled fabrication"* (Sacks et al, 2010)*;*

The current study combines "Online/Electronic Object-Based Communication" and "Collaboration in Design and Construction" as they both represent communication improvement through BIM channels and applications.

The BIM MMs attributes are compared below based on the BIM functionalities associated with the defined Lean principles in the matrix. The descriptions are based on Sacks et al. (2010).

3.1.1 Visualisation of form

"Visualisation of the form" refers to the engagement of all stakeholders, including non-technical parties, in all phases of design through high-quality rendering with some degree of realism. It supports a number of Lean principles, such as minimising variability, making a consensus decision during the design process, and capturing the client's requirements (Sacks et al. 2010).

The review of the MMs showed that "visualisation of the form" was usually absent in the attributes of BIM MMs with an organisational measurement scope. For instance, the Multifunctional BIM MM, Characterisation framework, BIM Quickscan, Organizational Assessment Profile, BIM Maturity Matrix, BIM-CAREM, and BiM^2FR which measure the BIM implementation in an organisation, do not discuss how this particular BIM functionality works their model structure.

In comparison, the majority of BIM MMs with a capacity for project measurement, propose to assess "Visualisation of the form" by evaluation of high-quality rendered images and 3D models. NBIM-CMM, VDCScorecard, and Arup BIM-MM have focused on project maturity assessment, including "visualisation of the form" as one of the essential uses of BIM. NBIM CMM enhances communication with non-technical participants through high-quality rendering and accurate geometry in the form of graphical information. Likewise, the "IU BIM Proficiency Matrix" and "Owners BIM CAT" have included model accuracy and high-quality geometry design within the established attributes as a channel to improve communication among the parties.

3.1.2 Rapid generation of multiple design alternatives

The use of BIM enables businesses to meet critical Lean values such as performance enhancement and waste reduction due to its ability to rapidly generate complex alternatives using object-based models (Sacks et al. 2010).

Among the BIM MMs investigated, the VDC scorecard, in particular, includes a question about an organization's capacity for the early production of a range of alternatives. Also, one of the critical questions in the BIM Characterisation Framework is the number of options made with BIM for construction projects. BIM-CAREM names maturity level 3 in the model as "Corporate-wide BIM deployment," where required changes and new alternatives are made to 3D models to meet the client's or site workers' requirements (Yilmaz et al. 2019a). BiM2FR's "level of responsiveness" attribute aims to ascertain the extent to which a request for information (RFI) can be instantly addressed by giving tailored alternatives. However, the generation of alternatives was not considered in the remaining studies cited in this paper.

3.1.3 Use of model data for predictive analysis of building performance

This functionality has three aspects: energy and structural analysis, cost estimation, and analysis of compatibility with client values, codes, and standards. These features support organisations in conducting collaborative design analyses from the early stages of the project and reaching a consensus on different aspects of design with the associated parties (Sacks et al. 2010).

NBIM-CMM, VDC scorecard, Arup, and BIM Quick Scan are among the BIM MMs that have considered energy analysis in their assessment process. For instance, the VDC Scorecard has multiple-choice questions about energy analysis, thermal comfort, acoustics, fire and smoke, construction safety, and daylighting analysis. Energy and environmental sustainability data requirements are listed as an operational competency in the Owners' BIM CAT MM. In the IU Proficiency matrix, site orientation and quantity take-off are dealt with, but no additional supporting information about these two categories is provided. According to their set and established BIM objectives, the VDC Scorecard, ARUP BIM MM, and BIM Characterisation framework provide extensive cost and time estimation (Wu et al., 2017). In the organisational maturity assessment process through BiM2FR, the assessor can indicate the extent of analysis of lighting, acoustics, energy performance, thermal comfort, quality, customer satisfaction, validation of spaces, etc. By contrast, in the Organizational Assessment Profile, BIM Multi-functional MM, and BIM Maturity Matrix, there is no factor regarding building performance analysis.

3.1.4 Maintenance of information and design model integrity

Through this functionality, different disciplines can benefit from early and consistent support of automated clash detection in various BIM models generated by different disciplines (Sacks et al. 2010).

The most BIM MMs address clash detection. "Construction clash detection" or "design collision detection" competency factors are beneficial functionalities that the relational database brings to the maturity model in Owners BIM CAT. In the integrated analysis section of the VDC Scorecard, "clash detection" is specifically outlined as a critical attribute. Likewise, the BIM Multifunctional Model includes physical clashes or conflicts between the different discipline elements or systems that can be assessed through the "clash detection analysis" sub-domain.

In contrast, there is no available information about this functionality in the Organization Assessment Profile, Characterization Framework, and BiM2PR. The possible rationale for the Organization Assessment Profile is that the consistency of BIM implementation and organisational strategy is much more important than adopting BIM use. Given the lack of additional information about the IU BIM Proficiency Matrix, collision detection functionality could not be assessed.

3.1.5 Collaboration in design and construction (collaboration in modelling)

The use of BIM can improve the maintenance of model integrity across all project stakeholders by allowing each of them to track changes to the model using a shared platform such as a Common Data Environment (CDE), as well as applying the Industry Foundation Classes (IFC) to improve interoperability and data exchange processes (Sacks et al. 2010).

For instance, NBIM-CMM measures the levels of interoperability maturity in the project when the organisation uses IFC to ensure a common form of information flows across the disciplines. Likewise, Arup BIM MM assesses the maturity of CDE implementation. In the BIM Maturity Matrix, integrity improvement is measured by real-time data sharing and continuous revisiting and documenting as the two subattributes of the model. IFC support in Owner's BIM CAT MM represents the degree of maturity in sharing and exchanging data for improved model integrity. BiM2FR also recognises collaboration in all project phases as part of the information exchange process by using IFC. At the highest level of maturity in BIM2FR, all data storage and exchange information are documented, reflected, and controlled to improve integration among all project parties.

3.1.6 Rapid generation and evaluation of construction plan alternatives

4D BIM allows the visualisation of construction progress and schedule. BIM enables users to link and reuse the 3D models in the 4D software to show the order and duration of tasks in a simulation. This can meet the "selection of an appropriate production control approach" from Lean principles (Sacks et al. 2010).

In NBIM-MM, "graphical information" is a model attribute that queries the connection of 3D models with cost and time information via visualisation interfaces. Arup BIM MM within the discipline assessment template has a 4D (construction sequencing) measure pursuing the degree of connection between the BIM model and the programme manager to track project progress.

In the VDC Scorecard and BIM2FR, 4D and construction progress modelling are recognised as critical model analyses. Visualisation and communication, model-based analysis, including project resource analysis, are possible with VDC Scorecard 4D simulations.

However, not all BIMMMs measure the quality of visualisation of construction progress. For instance, analysing the Organizational Assessment Profile, BIM Maturity Matrix, Multi-Functional BIM MM, BIM Quick Scan, and Owners BIM CAT reveals that 4D BIM use is not a major concern in these BIM MMs.

3.1.7 Direct information transfer to support computer controlled fabrication.

This BIM-Lean Interaction Matrix functionality focuses more on the communication channels, such as tools enabling information transfer support to improve computer-controlled fabrication of components (Sacks et al. 2010). This capability of BIM significantly reduces human error and supports the variability reduction idea in Lean. Similarly, business-to-business integration is possible between companies involved in construction projects based on product specifications derived from building models. Except for the IU BIM Proficiency Matrix, the VDC Scorecard, and BIM-CAREM, not all BIM MMs include this functionality. In the "process" dimension of the VDC Scorecard, organisations can choose from a list of many processes that have reaped the expected benefits from using VDC. In the provided answers, "tight synchronisation between design and fabrication" is a proposed process that can benefit from Virtual Design & Construction (VDC).

A comparison of the selected BIM maturity models against the BIM-Lean Interaction Matrix results is summarised in Table 4. According to the findings, the Organization Assessment Profile and BIM Maturity Matrix have fewer incorporated BIM uses or functionalities compared to other models. This could arise from the different scope evaluation methodology used in these two models.

In contrast, the BIM functionalities highlighted by Sacks et al. (2010) are matched with different variables in NBIM-CMM, ARUP MM, VDC Scorecard, BIM CAREM, and BiM2FR more than in other models. Regardless of their evaluation scope, most of the BIM MMs meet the "predictive analysis of building performance" criteria due to their offering measures related to cost, energy, schedule, etc., analysis.

Table 4: BIM MMs Comparison Based on BIM- Lean Interaction Matrix

BIM Maturity Models	**Visualisation of Form**	**Rapid Generation of Multiple Design Alternatives**	**Use of Model Data for Predictive Analysis of Building Performance**	**Maintenance of Information and Design Model Integrity**	**Automated Generation of Drawings and Documents**	**Collaboration in Design and Construction**	**Rapid Generation and Evaluation of Construction Plan Alternatives**	**Direct Information Transfer to Support Computer Controlled Fabrication**
NBIM-CMM	●		●			●	●	
VDC Scorecard	●	●	●	●			●	●
AP								
Arup	●		●		●	●	●	
BIM MM						●		
BIM Quick Scan			●			●		
IU BIM Proficiency Matrix	●		●					●
Characterisation Framework		●					●	
Owner's BIM CAT	●		●	●				
BIM-CAREM		●		●		●	●	●
BiM2FR		●	●			●	●	
BIM Multi-function MM				●				

3.2 BIM MMs comparison based on the LCMM key attributes

Nesensohn (2014) developed the Lean Construction Maturity Model (LCMM) as a PhD thesis. This quantitative model evaluates the attributes described and explained in the form of the statements in this tool. Uptake of LCMM requires collaboration between project agents and an external or internal assessor (Rodegheri and Serra 2020).Major evaluation factors in the model are "leadership", "philosophy", "people, processes, and systems", "outcomes and outputs," and "learning." After the assessment is completed, a report is presented in the form of a radar diagram associated with five levels of maturity: uncertain, awaking, systemic, integrated, and challenging. Rodegheri and Serra (2019), evaluated a case study applying existing Lean Maturity tools in Brazil and asserted that LCMM is the most suitable approach since it offers good result presentation and project final report classification.

The selected existing BIM MMs are analysed in this section to determine how they have approached Lean Construction from the organisational point of view based on LCMM. Each factor in LCMM has several key attributes; therefore, a colour-coding method was applied to understand how many of them can be addressed by the selected BIM MMs. The analysis started with the assignment of a score to each key attribute, and the total sum indicated the level of connection between the studied BIM MMs and LCMM. Red shows no match with variables in BIM MMs, yellow demonstrates that one or two key attributes are addressed in BIM MMs, and green shows the BIM MMs variables meet more than two attributes.

According to Table 5, there is little overlap between BIM MMs and LCMMs, and only a few MMs indicate a possible relationship between BIM and LC. While the VDC Scorecard has the highest total value, as indicated by the colour coding, it does not address all of the items in each section. At least two variables are considered by VDCScorecard in the "Customer Focus," "Culture & Behaviour," "Process and Tools," "Work Environment," and "Business Result" categories.

Table 5: BIM MMs Comparison Based on the LCMM Key attributes

		LCMM KEY ATTRIBUTES										
		Leadership	**Philosophy**		**People**			**Processes & System**		**Outcomes & Outputs**		**Learning**
		Lean Leadership	Customer Focus	Way of Thinking	Culture & Behaviour	Improvement Enablers	Competencies	Processes & Tools	Change	Work Environment	Business Results	Learning & Competency Development
BIM MATURITY MODELS	**NBIMS-CMM**	Yellow	Red	Yellow	Red	Red	Red	Red	Red	Yellow	Red	Red
	IU BIM Proficiency Matrix	Yellow	Red	Red	Red	Red	Red	Yellow	Yellow	Red	Yellow	Red
	BIM Maturity Matrix	Yellow	Red	Yellow	Yellow	Yellow	Red	Red	Red	Yellow	Yellow	Green
	BIM Quick scan	Yellow	Yellow	Yellow	Red	Red	Red	Red	Yellow	Yellow	Red	Yellow
	Characterization Framework	Red	Yellow	Red	Red	Green	Red	Yellow	Yellow	Red	Yellow	Red
	Organization Assessment Profile	Yellow	Red	Yellow	Green	Red	Red	Red	Yellow	Yellow	Red	Yellow
	VDC Scorecard	Yellow	Green	Red	Green	Yellow	Red	Green	Yellow	Green	Green	Yellow
	Owner's BIM CAT	Yellow	Yellow	Red	Yellow	Red	Red	Yellow	Yellow	Yellow	Red	Yellow
	ARUP	Yellow	Yellow	Red	Yellow	Red	Red	Yellow	Yellow	Red	Red	Red
	BIM multi-functional MM	Yellow	Red	Red	Yellow	Red	Red	Yellow	Red	Yellow	Red	Red
	BIM-CAREM	Red	Yellow	Red	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Green
	BiM2FR	Green	Green	Red	Yellow	Red	Yellow	Green	Green	Yellow	Yellow	Green

Red	No attribute is addressed
Yellow	1 or 2 key attributes are addressed
Green	More than 2 attributes are addressed

The BIM Maturity Matrix and the BIM Organizational Assessment Profile are the second and third most lean-oriented BIM MMs investigated in this paper, respectively. The NBIM-CMM model is positioned as the least Lean-oriented model. This could be related to the scope of the evaluation, which is mainly concerned with the information flow and data richness in the BIM model, while the LCMM's primary concern is the cultural and managerial components of Lean.

The outcome of the comparison of the existing BIM MMs against two targets, the BIM-Lean Interaction Matrix and LCMM models, is demonstrated in Table 6. In this table, a number has been assigned to a BIM MM, which shows how many attributes of the BIM-Lean Interaction Matrix, which mostly focuses on the operational aspects, and how many attributes in the LCMM, which mainly considers organisational culture, are addressed.

Table 6: Lean Construction Assessment Scope

	BIM Maturity Models											
LC Assessment Scope	**VDC-Score Card**	**Organisation Assessment Profile**	**ARUP**	**NBIM- CMM**	**BIM Quick Scan**	**BIM Maturity Matrix**	**IU Proficiency Matrix**	**Characterisation Framework (Project)**	**Owner's BIM CAT**	**BIM Multi-functional MM**	**BIM-CAREM**	**BiM2FR**
Operational	6	0	4	5	1	0	2	2	3	1	5	4
Organizational Cultural	15	7	5	3	5	8	4	3	7	4	6	12

4. IPD ORIENTED BIM MATURITY MODELS

The construction supply chain has a wide range of stakeholders, including owners, architects, engineers, general contractors, main sub-contractors, suppliers, and manufacturers. The existence of a significant number of participants needs a robust approach to support strong teamwork and information flow (Ling et al., 2020). However, traditional, frequently used project delivery methods such as Design-Build and Design-Bid-Build suffer from serious systematic problems such as (1) the disruption of good ideas; (2) limitations on collaboration and creativity; (3) poor coordination; and (4) pressure for local improvement at project expense as a whole (Salim & Mahjoob, 2020). IPD was developed to address these issues and was supported by the American Institute of Architects (AIA 2007). The IPD definition has been widely accepted as:

"*A project delivery approach that integrates people, systems, business structures, and practises into a process that collaboratively harnesses the talents and insights of all project participants to optimise project results, increase value to the owner, reduce waste, and maximise efficiency through all the project phases*" (AIA 2007).

The first IPD principle, "mutual respect and trust," examines project actors collectively rather than their individual performance." Early involvement of key participants" as well as "continued involvement of key participants" in all stages of the project, from design to project completion, are the key characteristics of IPD. Also, a project can be considered an IPD when the pool of "compensation and reward" is shared, and everyone understands the importance of team progress together to achieve the highest reward. "Collaborative innovation and decision-making" values the contributions of people from different levels in the project. "Project goals" and objectives in IPD are defined early, and every party has a clear view of the defined objectives. All parties follow "intensified planning" and are aware that efficiency comes with increased planning effort. "Open communication" makes people define and take on roles and responsibilities clearly; thus, there should be a "no blame" culture. The existence of "appropriate technology" is one of the key enabling factors in IPD construction projects. Technology and software facilitate functionality and interoperability between organisations with collaborative platforms.

"Organisation leadership" goes to the most capable person in the organisation with the required expertise in this type of contracting model. An IPD team should:

- identifying the most qualified participant as soon as possible;
- pre-qualify both individuals and firms;
- consider the possible engagement of stakeholders like insurers;
- define and agree on the common goals, values, and objectives;
- determine the best organisational structure for IPD;
- develop a standard agreement specifying the roles and responsibilities (AIA 2007).

The IPD phases distinguish it from other project delivery methods. In conventional project delivery methods, construction projects flow from pre-design, schematic design, design development, construction documents, agency permit/bidding, and construction. Unlike the traditional phases, IPD follows the different phases from conceptualisation, criteria design, detailed design, implementation documents, agency review, final buy-out, and construction.

Analysing the BIM MMs selected in this paper against these three characteristics led to a comparative matrix that outlines potential IPD characteristics in the existing BIM-MMs. According to the information in Table 7, even though the BIM Maturity Matrix and VDC Scorecard evaluate different scopes, they both significantly address the IPD Principals and IPD Team-up attributes. For instance, "collaborative decision making", "appropriate technology," and "open communication" are common IPD principles in these two models. Due to the availability of a shared information platform infrastructure, the appropriate technology is well addressed in most BIM MMs. Open communication principles are also achieved in BIM MMs, as roles and responsibilities are a major concern in most of them. The BIM Maturity Matrix, VDC Scorecard, and Owner's BIM CAT are models where the team-up attributes are partially addressed.

Table 7: BIM MMs Comparison Based on the LCMM Key attributes

BIM Maturity Models	Integrated Project Delivery															
	IPD PRINCIPLES									**IPD TEAM UP**						**IPD PHASES**
	Mutual Respect & Trust	**Benefits and Rewards**	**Collaborative Decision Making**	**Early involvement**	**Early Goal Definition**	**Intensified Planning**	**Open Communication**	**Appropriate Technology**	**Organisation & Leadership**	**Early competent participant identification**	**Pre-qualification**	**Engagement of stakeholders**	**Common Goals, values and objectives**	**organisational structure**	**Developing a common agreement**	
IU Proficiency Matrix			●				●	●	●							
VDC Scorecard	●		●	●	●			●	●		●	●				
NBIM-CMM							●	●								
BIM Quick Scan	●							●								
Organisationa Assessment Profile						●	●									
ARUP			●						●							
BIM Maturity Matrix		●	●			●	●	●					●	●		
BIM Multi-Functional MM	●						●	●								
BIM Characterization Framework							●	●								
Owner's BIM CAT	●					●	●	●								
BIM-CAREM								●	●	●	●					
BiM2PR	●	●						●				●				

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5. CONCLUSION AND FUTURE WORK

This article presented a novel reflection of the inclusion of LC and IPD related attributes in ten selected BIM maturity models (MMs). The primary value of this research is to increase the understanding of practitioners and researchers on BIM interaction with LC and IPD. This will support the development of improved BIM-IPD-LC (BIL) MMs. BIM MMs at this stage are analysed first due to the number of them and recognition among the academics and industry practitioners. The next stage of this study will compare the range of BIM, IPD and LC models individually or in collaboration to reveal the potential interaction among these three construction approaches.

This research has studied interactions between BIM and LC based on two widely cited and accepted models: the BIM-LC Interaction matrix and the LCMM. It was revealed that the identified LC concepts and key attributes are not aligned in the majority of existing BIM MMs from both cultural and operational perspectives. Among all the studied models, the VDC Scorecard and BiM2FR support the widest range of LC principles and hence can contribute to the development of future BIL MMs.

Also, this study showed the level of interaction between BIM and IPD according to information provided by the AIA IPD guide. The discussion of the results and the identified implications showed that the BIM MMs' structures do not fully support IPD requirements, where IPD "Principles", "Team Up" strategies, and "Phase" are not sufficiently addressed by the models. Most BIM MMs partially meet "open communication" and "appropriate technology" due to the communicative and technical nature of BIM. However, there were no examples of "early goal definition" or "early involvement of stakeholders" in a significant number of models. The lack of consideration of LC and IPD attributes in the BIM model can be related to a lack of available collaborative BIM implementation with IPD and LC, as well as the infancy of each in practice.

The findings of this study provide input for the identification and formulation of attributes for an integrated BIM-IPD-LC maturity model. The identified attributes associated with the collaborative relationship of BIM, IPD and LC can guide the researchers or professionals who intend to structure the related MMs.

Future works can also examine and investigate the factors that impede the consideration of LC and IPD in BIM MMs. Furthermore, future research can present directions on how these identified factors can be addressed to formulate LC and IPD related BIM MMs. With increasing clarity and awareness around the BIM MMs in recent years and the interaction of BIM with IPD and LC, future BIM MMs can also provide a more explicit approach to be integrated into BIL.

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