Measuring building information modeling maturity: A Hong Kong case study

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Abstract

Building Information Modeling (BIM) has been lauded as a "game changer" for the construction industry. Growing studies show a strong interest among researchers and practitioners to assess the maturity of BIM implementation, which helps understand its quality and degrees of excellence. However, no single study to date has comprehensively measured BIM maturity at the project, organisation, and industry levels and thus achieved a holistic view of BIM implementation. Therefore, this study aims to measure BIM maturity at these three scales using Hong Kong's construction context as a specific case. To this end, this study collected publicly available information of BIM implementation projects and adopted the multifunctional BIM maturity model (MBMM) as the measurement tool. The results found that construction projects in Hong Kong vary in terms of BIM maturity, with more than half ranging from Stage 0 to 1. The study also discovered that the BIM maturities of construction-related organisations in Hong Kong differ from each other, primarily owing to the different developments of their BIM processes and protocols. The industry-level assessment indicated unbalanced development in BIM technologies, processes, and protocols. The value of this study is three-fold. Firstly, it provides an in-depth understanding of BIM maturity in Hong Kong. Secondly, it contributes to BIM maturity measurement by highlighting the dynamics of BIM technologies, processes, and protocols at the project, organisation, and industry levels. Thirdly, it offers operational procedures for BIM maturity measurement.

Keywords: Building Information Modeling (BIM), maturity, measurement, Hong Kong

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1. Introduction

Building Information Modeling (BIM) has been widely adopted by the global construction industry over the past two decades (Lu et al. 2017a; Zheng et al. 2017; Ahuja et al. 2018; Liao and Teo 2018). A survey conducted by McGraw-Hill Construction (2012) reported that the industry-wide BIM adoption in North America skyrocketed from 28% to 71% between 2007 and 2012. NBS (2018) reported that BIM adoption in the U.K. increased from 13% in 2011 to 74% in 2018. Similar trends in BIM adoption have occurred in Mainland China, Hong Kong, Singapore, Australia, and so on. This upsurge raises some essential concerns about the quality and degrees of excellence in BIM implementation, *i.e.*, the BIM maturity (Succar 2009a).

Measuring BIM maturity has attracted the attention and efforts of both industry and academia. Available publications reporting on BIM maturity overwhelmingly relied on survey ratings from commercially-driven service providers, such as the aforementioned McGraw-Hill Construction and NBS. However, industry surveys often used single indicator, *e.g.*, the number of years stakeholders have been using BIM, for representing the status of BIM maturity. Besides these industry surveys, other researchers investigated BIM maturity at the market-scale in the U.S. (Chen et al. 2014), Australia (Gu and London 2010), The Netherlands (Sebastian and van Berlo 2010), etc. Although these studies absolutely provide valuable insight into BIM maturity, the following two important aspects of BIM maturity measurement were overlooked.

Firstly, the mature implementation of BIM necessitates changes in all business aspects including technology, process, and protocol. Technology and process root in that BIM, by definition, constitutes a host of information technologies and a set of associative processes, *e.g.*, BIM workflows and model coordination mechanisms (Eastman et al. 2011). Protocol, under this circumstance, refers to the interfaces, BIM roles and responsibilities, etc. (Singh et al. 2011; Rezgui et al. 2013). Therefore, the measurement of BIM maturity should cover these three domains comprehensively. Secondly, it is important to measure BIM maturity at different levels, *e.g.*, project, organisation, and industry levels. A clear understanding of BIM maturity at the project and organisation scales helps organisations identify a particular project' achievements using BIM and inform further strategies concerning BIM implementation within the organisation (Arup 2015). A knowledge of BIM maturity at the industry level can reveal the status quo of BIM adoption in the marketplace of a given region or country, as well as standardize BIM tools and workflows for that market (Succar and Kassem 2015).

This study aims to advance the measurement of BIM maturity at the project, organisation, and industry levels using the case of Hong Kong. Hong Kong is selected as the research context given the region is in the early stage of BIM adoption (Hong Kong Construction Industry Council [HKCIC] 2014 p. 8). To maintain momentum, a clear direction for the improvement of BIM maturity must be established. As expressed by the HKCIC (2014 p. 9), stakeholders "wish to see a more organised and systematic approach that drives the industry-wide adoption of BIM in Hong Kong through the concerted efforts of the construction industry". In this study, the multifunctional BIM maturity model (MBMM) introduced by Liang et al. (2016) is adopted as the measurement tool due to two reasons. Firstly, MBMM covers the three domains integral to BIM implementation, *i.e.*, technology, process, and protocol. Secondly, MBMM allows the measurement of BIM maturity at the project, organisation, and industry levels. The derived results thus can interpret BIM-enabled achievements attained over the years of BIM practice in Hong Kong.

This study yields three major contributions. Its findings offer an overall picture, as well as an in-depth understanding of BIM maturity in Hong Kong, which allows stakeholders to make their own BIM implementation strategies. Moreover, this study contributes to the knowledge body of BIM maturity measurement by highlighting the dynamics of BIM technologies, processes, and protocols at the project, organisation, and industry levels. Lastly, it provides researchers and industrial practitioners with the procedures necessary to measure BIM maturity in other economies beyond Hong Kong for various purposes, *e.g.*, stocktaking or crafting BIM implementation strategies.

The remainder of this paper reads as follows. Section 2 provides an overview of current BIM implementation and introduces existing BIM maturity models, which includes MBMM, subsequently used in this study. Section 3 briefly describes the research methods. Section 4 presents the results of the case study, while Section 5 offers an in-depth discussion of the results. Section 6 summarizes and concludes this study.

2. Literature review

2.1 Overview of BIM implementation

McGraw-Hill Construction, recently renamed Dodge Data and Analytics, has published a series of reports on BIM implementation in different regions and countries. Some of which, such as the U.S., Denmark, and Singapore, have formally endorsed the implementation of BIM in the construction industry either by establishing BIM standards and protocols or mandating BIM use in government projects (Cheng and Lu 2015). The General Services Administration (GSA) in the U.S. has required BIM submission for major federal government building projects since 2008. The European Commission awarded the European Union BIM Task Group funding to deliver a common European network for aligning the implementation of BIM in public works. In addition, the Building and Construction Authority of Singapore has demanded the submission of BIM models in native format since 2017. Even if not federally endorsed, BIM implementation has been progressing in many other regions and countries. For instance, the Hong Kong Housing Authority has published its in-house BIM user guides for stakeholders participating in public housing projects and over forty government pilot projects have adopted BIM since 2015 (Development Bureau 2017).

The proliferation of BIM in the construction industry has led many studies to gauge the benefits of BIM at the project, organisation, and industry levels (*e.g.*, Ghaffarianhoseini et al. 2017; Zheng et al. 2017). Giel and Issa (2013) suggested the majority of BIM users see value in using BIM but fail to use BIM to its full potential. Yang and Chou (2018) identified the varying types and degrees of practical BIM implementation between districts, stakeholders, and projects. Such inconsistency in BIM implementation calls for the institution of BIM maturity measures. Since measurement verifies improvement and helps manage performance, BIM cannot be successful without measuring practices (Chen et al. 2014). BIM is not a one-dimensional concept or an end-product, and its implementation often requires changes in processes, protocols, and technologies (Succar 2009a). Hence, the measurement of BIM maturity should consider these domains and how to interact with them at the project, organisation, and industry levels for the sake of facilitating the improvement of BIM implementation (Chen et al. 2014; Liang et al. 2016).

2.2 BIM maturity models

Some previous studies such as Succar (2009b), Sebastian and van Berlo (2010), Chen et al. (2014), and Kam et al. (2016) conducted empirical investigations of BIM maturity at different levels. Along with the investigation of BIM maturity, a number of BIM maturity models have been proposed. These models have their own strengths, weaknesses, and applicability as shown in Table 1.

<Please insert Table 1 here>

Capability Maturity Model (CMM)

CMM, outlined in the national BIM standard (NBIMS), represents one of the most commonly adopted BIM assessment tools in the U.S. (McCuen et al. 2011). It allows BIM users the means to evaluate their current BIM implementation practices and processes. CMM can also help BIM users set goals for achieving higher levels of BIM maturity in future. However, CMM is an internal tool for assessing the maturity level of individual BIM models against a set of pre-defined weighted criteria. Therefore, CMM cannot be used to compare different BIM models or implementations and measure the BIM maturity of an organisation or the industry as a whole.

BIM Maturity Index (BMI)

BMI, developed by Succar (2009b), is the first model capable of narrowing down issues related to BIM maturity. It does so via three fields, *i.e.*, policy, process, and technology, and five distinct maturity levels, *i.e.*, initial/ad-hoc, defined, managed, integrated, and optimized. However, BMI only delivers a set of blueprints of what future capability maturity of BIM should be. In addition, the components clustered in each of these three fields are poorly defined, which limits measurement results to merely rough estimates.

BIM Proficiency Matrix (BPM)

Indiana University's BPM can help measure the proficiency of a respondent's BIM implementation (IU 2009). The overall score of BPM is measured by adding the evaluation results from eight perspectives, *i.e.*, physical accuracy of model, Integrated Project Delivery (IPD) methodology, calculation mentality, location awareness, content creation, construction data, as-built modeling, and facility management data richness. Each perspective further subdivides into four more detailed areas, which helps dissect the BIM working environment. However, BPM has received criticism. Seven out of its eight perspectives are designed for assessing the technical aspects of BIM implementation, while the process and protocol aspects of BIM implementation are not comprehensively covered.

BIM QuickScan

BIM QuickScan, proposed by Sebastian and van Berlo (2010), is intended to assess the BIM performance of organisations and establish performance benchmarks. It contains fifty multiple-choice online questions grouped into four chapters including organisation and management, mentality and culture, information structure and information flow, and tools and applications. These four chapters incorporate organisation and technology issues related to BIM performance. The obvious limitation of BIM QuickScan is its failure to provide methods and procedures for identifying these four chapters. Therefore, convincing BIM users that the assessment result reflects their actual BIM maturity is extremely difficult.

Virtual Design and Construction (VDC) Scorecard

The Center for Integrated Facility Engineering (CIFE) at Stanford University developed VDC Scorecard to be the first tool to measure BIM maturity based on a large set of project information. The VDC Scorecard exercises a three-tiered measurement framework. The first includes planning, adoption, technology, and performance. The second has ten divisions, *i.e.*, objectives, standards, preparation, process, organisation, maturity, coverage, integration, quality, and quantity. The third incorporates fifty-six measurements (Kam et al. 2016). VDC Scorecard is project-oriented. The final score of each project is the weighted sum of the four areas' scores, where the percentage of weight is determined by confidence level from the respondents in order to reduce the uncertainty from the project. Although VDC Scorecard has the benefit of continuously aligning with industry practice, it cannot be used to verify the BIM maturity of an organisation.

BIM Measurement Model (BMM)

BMM, developed by Chen et al. (2014), clearly takes as a point of departure previous studies on using empirical investigation to identify key factors for measuring the maturity level of BIM implementation. Factors were selected based on a review of existing studies and an online questionnaire with a seven Likert scoring system. Afterwards, a two-step approach, *i.e.*, exploratory factor analysis and confirmatory factor analysis, were adopted to further investigate hidden patterns in the maturity factors of BIM implementation (Chen et al. 2014). However, BMM largely borrows factors from existing maturity models, which lack significant information on BIM standards. In this regard, BMM may need frequent updating in order to keep track of the most recent practical issues facing BIM.

Multifunctional BIM Maturity Model (MBMM)

Responding to the absence of development procedure documentation amongst the prevailing BIM maturity models, Liang et al. (2016) adopted a three step, reiterative approach to developing MBMM. In MBMM (see Fig. 1), the three domains, *i.e.*, technology, process, and protocol, are organised in a hierarchical pyramid. Each domain has subdomains. For example, the technology subdomains include information accuracy (T1), model data (T2), quality assurance and quality control (T3), data security and saving (T4), technology infrastructure needs (T5), BIM elements (T6), and finally spatial and coordination (T7). Detailed, operable rubrics enable the assessment of each subdomain, while the assessment result points to a specific stage (0–3). Most rubrics contain evaluative criteria, quality definitions for the criteria at particular levels of achievement, and a scoring strategy that allows presentation in table format and assessment.

<Please insert Fig. 1 here>

Apart from comprehensively including the three domains inherent to BIM implementation and integrating them into a single, intuitive presentation, another central characteristic of MBMM is its ability to measure BIM maturity at different scales from individual projects to an organisation's full projects portfolio. MBMM helps condense these projects' BIM maturity stages and portray the organisation's overall BIM maturity. More impressively, MBMM allows for analysis at the national economy level. By collecting the case histories of numerous organisations providing the same or similar functions (Dubois and Gadde 2002) and mainly adopting a project-based organisation form to deliver construction works (Pryke and Pearson 2006), MBMM captures the traits of the construction industry. These unique features make MBMM a more suitable measurement tool for this study than the other above-mentioned BIM maturity models.

3. Research methods

This study follows a three-step research design. The first step – data collection – involves sifting through documented information about real-life BIM implementation projects conducted locally in Hong Kong. The second step is to measure BIM maturity of the combed projects using MBMM. In this step, BIM maturities at the organisation level and industry level stem from the BIM maturities of projects. The third step, based on the measurement results, entails the analysis of BIM maturity in the Hong Kong context.

3.1 Data collection

Publicly available data makes up the primary data source for this study. Several precedents exist to defend the use of online data for BIM maturity measurement. For example, Kassem et al. (2013) use “noteworthy BIM publications (NBPs)” and “BIM knowledge content (BKC)” for the comparison of various countries’ BIM maturities. For this study, the authors utilized Google’s search engine to collect BIM implementation projects that fulfil two criteria, *i.e.*, the project was located in Hong Kong and disclosed any and all project information related to BIM implementation for maturity measurement by MBMM. Subsequently, the authors scrutinized each of their accumulated projects to determine whether it merited further analysis. Through this process, a total of twenty-one documented BIM implementation projects in Hong Kong was obtained. Nineteen of which came from the Autodesk’s online BIM project database and occurred between 2010 and 2014 (Autodesk 2016). The remaining two, *i.e.*, the One Island East and the Cathay Pacific Cargo Terminal, derived from Baldwin and Bordoli (2014) and Staub-French et al. (2011) respectively. These projects include residential buildings (*e.g.*, Public Rental Housing at Shatin Area 52 Phase 1), commercial buildings (*e.g.*, One Island East), institutional buildings (*e.g.*, Innovation Tower at Hong Kong PolyU), airport facilities (*e.g.*, Cathay Pacific Cargo Terminal), and railway facilities (*e.g.*, Hung Hom Station and Approach Tunnels). They offer practical representations of BIM implementation in Hong Kong.

3.2 Data interpretation

When applying MBMM, a real-life BIM implementation project is first examined against the rubrics. Its final scores for each of the three BIM maturity domains are plotted, indicating the project’s overall BIM maturity (see Fig. 2). If an organisation has a portfolio of BIM implementation projects on hand, repeating the procedure for each project and summating the weighted results in MBMM reveals the institution’s overall, *i.e.*, organisation-level, BIM maturity. In a similar vein, the weighted summation of all surveyed organisations’ BIM maturities helps expose the industry-level BIM maturity. Finally, an overall measurement of BIM maturity, *i.e.*, Stages 0, 1, 2, and 3, can be derived (see Table 2).

<Please insert Fig. 2 here>

<Please insert Table 2 here>

Each project’s collected documents are scanned for keywords or descriptions that match or relate to the rubrics’ criteria and then summarized into an algebraically derived score (*i.e.*, using weighted summation). This process helps identify the maturity stage of each subdomain. As the information in these documents is mainly descriptive, a human-led coding process is employed for repackaging the qualitative data against the rubrics. For any projects, if there is no such information about specific subdomains, *e.g.*, interoperability/IFC support or standard operating process, the subdomains' measurement results receive a N/A mark and termed zero. To counteract the rubrics' subjective element, *i.e.*, human-led coding, the statistical technique Cronbach's alpha is applied, whereby individual researchers read and code reports independently following the form shown in Fig. 2. The closer Cronbach's alpha to 1.0, the more in agreement were the specialists' measurements (Olawumi and Chan 2018).

4. Results and analyses

In this study, three local experts interpreted the twenty-one BIM implementation projects' information using Delphi method. In Round 1 Delphi, the experts were asked to mark the score of each subdomain of MBMM against the rubrics as introduced in Section 3. In Round 2 Delphi, the experts were asked to reassess their interpretation in light of the consolidated results from Round 1. The Cronbach's alpha reached over 0.9, indicating significant agreement among the experts. Then, by taking the average, the measurement results materialized as summarized in Table 3. Based on the measurement results, analyses on the BIM maturity at different levels are presented as follows.

<Please insert Table 3 here>

4.1 Project-level analysis

The studied projects' BIM maturities mostly fall between Stage 0 and 1. No project demonstrated Stage 2 BIM maturity (see Table 3). The One Island East (hereinafter referred to as Project A) and the Cathay Pacific Cargo Terminal (hereinafter referred to as Project B) are chosen as the examples to demonstrate BIM maturity analysis at the project level. Project A concerns a high-rise commercial office building with sixty-eight floors above ground and two below. The total floor area is around 141,000m^2 and the overall project cost is approximately US$300 million. Project A's participants, *e.g.*, the architects, quantity surveyors, structural engineers and BIM technology specialists, worked together to create a unique 3D BIM project database. BIM facilitated clash analysis of the design prior to breaking ground, thus enabling improved team coordination, cost savings, and keeping on schedule as well. During construction, BIM served as a central management instrument, providing project members and stakeholders real-time lifecycle process information for the entire building via an Internet-based project database.

Project B is an eight-story building with a total area of roughly 22,854m^2. One of the largest air cargo terminal buildings in the world, Project B's construction lasted from 2010 to 2013 and cost approximately US$700 million. The BIM database for Project B was well developed, encompassing the virtual design, *e.g.*, 2D to 3D model conversion, architectural rendering and animation, clash detection, and 5D modeling, *i.e.*, cost and time dimensions. BIM also expedited communication between stakeholders (Staub-French et al. 2011).

Fig. 3 presents these two projects' BIM maturities. The overall BIM maturity score for Project B is 1.190, slightly higher than Project A's 1.048 (see Table 3). This is mostly due to Project B earning higher process and protocol domains than Project A. In contrast, results in the technology domain went against expectations with Project B scoring lower than Project A despite the former beginning in 2010 and the latter in 2006. This result could suggest that obstacles to BIM maturity relate more to processes and protocols than the advancement of technology.

<Please insert Fig. 3 here>

4.2 Organisation-level analysis

To reiterate, the BIM maturities of organisations in Hong Kong differ from one another primarily because of the different developments in BIM process and protocol. Two organisations demonstrate BIM maturity analysis at the organisation level. Organisation C, a government authority acting as the main provider of public housing in Hong Kong, accommodates about fifty percent of the city's population (Hong Kong Information Services Department [HKISD] 2016). Organisation C began exercising BIM in its public housing projects in 2006 and now mandates BIM on all projects from design visualization through construction. In 2009, Organisation C sourced BIM to develop a standard modular flat and design library. Organisation C has also published multiple BIM user guides, a BIM library component design guide, and a BIM library component reference for BIM implementation (Hong Kong Housing Authority [HKHA] 2016).

Organisation D, a limited company and major property developer in Hong Kong, also manages and operates Hong Kong's Mass Transit Railway. Organisation D has been exploring the use of BIM to support the development of new lines and other rail projects (Mass Transit Railway Corporation [MTRC] 2015). Organisation D's BIM models typically contain the architecture and structure specifications of the railway projects, either provided in-house or by professional BIM service providers. Organisation D has used BIM to deploy new procurement models for upcoming railway projects to expand resources upfront, improve communications and coordination, reduce construction costs, and save time (Autodesk 2016).

Fig. 4 illustrates the BIM maturities of Organisations C and D. In all three domains (*i.e.*, technology, process, protocol), Organisation C scores higher than Organisation D. For example, the BIM maturity scores of Organisation C's projects, "Construction of Public Rental Housing at Sha Tin Area 52 Phase 1" and "Transformation of Revit Model to Enable Civil 3D/GIS/Revit Integration and Lighting Simulation and Rendering", are 1.667 and 1.905 respectively. In contrast, the BIM maturity scores of Organisation D's projects mainly cluster around 1.0 (see Table 3). Several reasons potentially explain these differences. Firstly, Organisation C faces perhaps fewer obstacles and challenges to BIM implementation in its public housing projects than Organisation D. Secondly, Organisation C may have a stronger capacity to maintain the excellence of BIM performance across different project stages. While the unique features of Organisation D projects prevent BIM practitioners from repeating implementation patterns. Thirdly, Organisation C has developed in-house BIM user guides, which can be particularly important for those project teams unfamiliar with the use of BIM, while Organisation D lacks such provisions.

<Please insert Fig. 4 here>

4.3 Industry-level analysis

Summarizing the measurement results of Table 3, Fig. 5 shows the scatterplot depiction of the overall BIM maturity assessment at the industry level. The points do not cluster or form any pattern, indicating that the BIM practice in some projects and some organisations in Hong Kong remain in the exploratory or start-up stages. One possible explanation for this could be construction stakeholders in Hong Kong take an exploratory approach to BIM implementation, piloting BIM technologies, processes and protocols in some trades or sections of projects in order to gain experience before developing an organisation-level BIM implementation strategy. Despite the lack of pattern, in general, the scatterplot reveals an exponentially upwards trajectory for BIM maturity in Hong Kong and the BIM maturities of some recent projects approach Stage 2. This suggests BIM systems are advancing, models are becoming moderately more accurate, and BIM responsibilities, more specified, perhaps to a particular BIM department within an organisation. It also implies modeling processes, compensation, and facility data are standardizing.

<Please insert Fig. 5 here>

5. Discussion

The measurement of BIM maturity in Hong Kong reveals several important findings of BIM implementation through years of efforts in Hong Kong. The most important likely concerns the unbalanced development of the three domains which define BIM maturity, *i.e.*, the development of BIM protocols offsets the development of BIM technologies and processes. The fact that most construction organisations in Hong Kong lack in-house BIM standards (Chen et al. 2017) possibly explains this imbalance, *i.e.* their maturities of BIM protocols are still in the start-up stage. Although the HKCIC published a BIM roadmap and series of corresponding standards in 2015 (HKCIC 2015), individual organisations have yet to fully adopted them. As one size does not fit all, a general industry-level BIM standard must be translated by individual organisations into personally operable guidelines, which takes time (Lu et al. 2017b). Organisation C's relatively high BIM maturity score in the protocol domain indicates that by following the industrial standard and gaining familiarity with BIM practice, organisations can develop legitimate and reasonable procedures to approach BIM maturity gradually.

As argued by Liang et al. (2016), Chen et al. (2014), Gu and London (2010), and others, the development of BIM technologies, processes, and protocols must align in order to cultivate the full benefits of BIM. Based on the measurement results presented in this study, different parties can and should set their own priorities to implement BIM at higher maturity levels. Government organisations should further provide implementation guidelines to industrial stakeholders, especially those who have less experience implementing BIM. Government organisations can also support universities and institutions by providing training courses and programs that introduce and demonstrate BIM technologies. Moreover, stakeholders, who may not need to be at the highest stages of all three BIM maturity domains, can select their own suitable target stage for a BIM project. However, if stakeholders seek to achieve higher stages of BIM implementation process, *i.e.*, beyond Stages 0 and 1, they can inject more resources into formalizing their processes related to BIM. While stakeholders already in possession of sufficient experience implementing BIM may shift their attention to the development of BIM protocols and technologies.

During the application of MBMM, the authors also noted the importance of standardizing project reporting. Compiling and reporting information using generally accepted international metrics and standard conversion factors (Global Reporting Initiative [GRI] 2016) promotes the facilitation of communication with the public and increases the accuracy of what is reported. Unfortunately, organisations in Hong Kong seem not to be documenting their BIM implementation well or investing in standardized project reporting. This study focused on the twenty-one projects capable of fully interpreting through by MBMM despite there could be more examples of BIM implementation projects in Hong Kong. Therefore, the authors advocate the standardization of reporting in BIM implementation projects for which MBMM offers a framework. With more BIM implementations being well documented in a standardized manner, the results of BIM maturity measurement can prove more comprehensive and other relevant research can be conducted. For example, MBMM can be linked to BIM-related topics like IPD (Teng et al. 2017) and other procurement innovations (Lu et al. 2013) to examine their impacts on the process and protocol domains of BIM maturity.

6. Conclusion

BIM is an emerging field and as such, its maturation has yet to be fully understood. The development and application of BIM maturity models provide useful references for demystifying the maturation of BIM in a certain context. A comprehensive understanding of BIM maturity and its measurement results are important for many strategies toward improved use of BIM, such as the development of a standard means of practice, training arrangements, and technology deployment.

This paper measures BIM maturity at the project, organisation, and industry levels within Hong Kong's construction context. The measurement results uncover the overall unbalanced BIM development in Hong Kong in terms of technologies, processes, and protocols. Regarding the BIM maturity at the project level, although more than half of the examined projects use BIM with maturity ranging from Stage 0 to 1, some recent projects appear to approach Stage 2 BIM maturity. At the organisation level, it was found that BIM has uniquely matured in different construction organisations. An organisation that faces fewer obstacles in BIM implementation and has developed its own BIM standards will likely achieve a higher BIM maturity stage. Although this study focuses on Hong Kong, researchers and industrial practitioners can apply

MBMM, following the procedures presented in this study, to measure BIM maturity in other economies.

This study exhibits some limitations that should be addressed by future research. Firstly, the assessment process employs rubrics that contain an inherent degree of subjectivity. Secondly, most of the BIM implementation projects used in this study are collected from the Autodesk BIM project database as the documented BIM implementation projects are relatively limited so far. The increased availability of 'effectively' reported projects is expected to rectify this dilemma. The authors, therefore, advocate the standardized reporting of BIM implementation projects with a view to enabling more comprehensive BIM maturity measurement.

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Table 1 Summary of BIM maturity models

Model	Strengths	Weaknesses	Applicability
Capability Maturity Model (CMM)	Simple structure; Easy implementation.	Low flexibility; Limited scope; Measurement results are highly subjective;	Project
BIM Maturity Index (BMI)	Easy implementation; Covering policy, process, and technology aspects.	Measurement results are highly subjective; Too vague and slack;	Organisation
BIM Proficiency Matrix (BPM)	Simple structure; Easy implementation. High flexibility.	Measurement results are highly subjective; Limited scope to technical aspects of BIM implementation;	Project
BIM QuickScan	Incorporating organisation and technology issues; Extensive scope.	Difficult to use; Less reliable without consultant services.	Organisation
Virtual Design and Construction (VDC) Scorecard	Results are more objective; High flexibility; Extensive scope; Providing benchmarking system.	Difficult to use; Time and resources exhaustive.	Project
BIM Measurement Model (BMM)	Results are relatively reliable.	Limited scope.	Project
Multifunctional BIM Maturity Model (MBMM)	Single, intuitive presentation; Covering technology, process, and protocol aspects.	Measurement results are relatively subjective.	Project; Organisation; Industry

Table 2 Summary of BIM maturity Stages 0, 1, 2, 3 as defined in MBMM

	Technology	Process	Protocol
Stage 0	The rough model contains inaccurate but indicative data. There is no data security or no IT infrastructure supporting the use of BIM.	There is no data exchange or conduct of analytic work, and no clear objectives or management support for BIM implementation.	There is no interoperability, and no standards, responsibilities, compensation, or requirements related to BIM implementation.
Stage 1	The model is slightly accurate with its data and elements meeting the basic requirements for BIM implementation. Both hardware and software support basic BIM systems, and data security is established within the BIM team of the organisation.	BIM implementation only has a few objectives with limited management support. Data and model exchanges are limited.	The Industry Foundation Classes (IFC) is used for interoperability. Operating and modeling process, compensation, and facility data are not standardized. BIM responsibility is specified for the BIM technical leader of the organisation.
Stage 2	The model is moderately accurate with its data and elements meeting the organisation's standards. Both hardware and software support advanced BIM systems, and data security is established within the organisation.	Data and model can be exchanged within individual organisations through available web services, following their own standards. BIM implementation can have specific objectives with moderate management support.	IFC and Information Delivery Manual (IDM) are used for interoperability of most of information. Operating and modeling process, compensation, and facility data are standardized within the organisation. BIM responsibility is specified for the BIM team of the organisation.
Stage 3	The model is completely accurate with all its data and elements meeting industry standards. Both hardware and software are available for continuous updating, and data security is established within the industry.	Data and model can be exchanged and accessed freely through secured web service, following industry standards. BIM implementation can have continuously-updated objectives with full management support.	IFC and IDM are used for interoperability of all information. Operating and modeling process, compensation, and facility data are standardized within the industry. BIM responsibility is specified for the whole organisation.

Table 3 Maturity assessment results of BIM implementation projects

	Project Name	AAY	ECY	Technology	Process	Protocol	Overall
1	Express Rail Link-West Kowloon Terminus Building (Aedas)	2010	2015	1.286	1.000	0.857	1.048
2	Redevelopment of Hennessy Centre (Gammon Construction Limited)	2010	2012	0.714	1.143	0.286	0.714
3	Shatin to Central Link (Mass Transit Railway Corporation)	2010	2019	0.571	1.286	0.571	0.810
4	Kai Tak Nullah Improvement Works at Prince Edward Road East (Scott Wilson Limited)	2010	2012	0.571	0.571	0.143	0.428
5	Innovation Tower, School of DesignDevelopment, PolyU (Shui On Construction Company Limited)	2011	2012	0.857	1.500	0.571	0.976
6	Commercial Development at 135-137 Hoi Bun Road (AECOM)	2011	2013	0.714	0.714	0.286	0.571
7	Development of a luxurious boutique hotel (Henderson Land Development Co. Ltd.)	2011	2011	1.000	0.714	0.286	0.667
8	Construction of Public Rental Housing at Shatin Area 52 Phase 1 (Hong Kong Housing Authority)	2012	2014	1.857	1.714	1.429	1.667
9	Express Rail Link – WestKowloon Terminus Building (Mass Transit Railway Corporation)	2012	2015	0.571	1.429	0.857	0.952
10	Blue Pool Road Residential Development (Hang Lung Properties Limited)	2012	2013	1.000	1.143	0.857	1.000
11	Commercial Development Project at 28 Hennessy Road (Hsin Chong Construction Group Limited)	2012	2012	1.286	1.286	0.714	1.095
12	Hung Hom Station and Approach Tunnels (Mass Transit Railway Corporation)	2013	2018	1.143	1.000	0.429	0.857
13	The University Heights Redevelopment (Chinachem Group)	2013	2017	0.857	0.857	0.714	0.810
14	EMAX Phase II (Hopewell Property and Facility Management Limited)	2013	2014	0.857	0.714	0.571	0.714
15	Midfield Development Design Consultancy Services (Mott MacDonald and Arup)	2013	2015	1.143	1.000	0.429	0.857
16	Transformation of Revit Model to Enable Civil 3D/GIS/Revit Integration and Lighting Simulation and Rendering (Hong Kong Housing Authority)	2014	2014	2.000	2.143	1.571	1.905
17	Re-provisioning of Harbor Road Sports Centre and Wan Chai Swimming Pool (Mass Transit Railway Corporation)	2014	2017	1.429	1.143	0.857	1.143
18	West Kowloon Reclamation Substation (CLP Power Hong Kong Limited)	2014	2016	1.517	1.428	1.000	1.333
19	Proposed Office Development at 14-30 King Wah Road (Henderson Land Development Co. Ltd.)	2014	2016	1.714	1.143	0.857	1.238
20	One Island East Tower (Gammon Construction Limited)	2006*	2008	1.143	1.286	0.714	1.048
21	Cathay Pacific Cargo Terminal (Intelibuild)	2010*	2013	0.857	1.571	1.143	1.190

Note: 1. AAY = award announcement year; ECY = expected completion year

2. In rows 20 and 21, “*” indicates the project commencement year instead of award announcement year

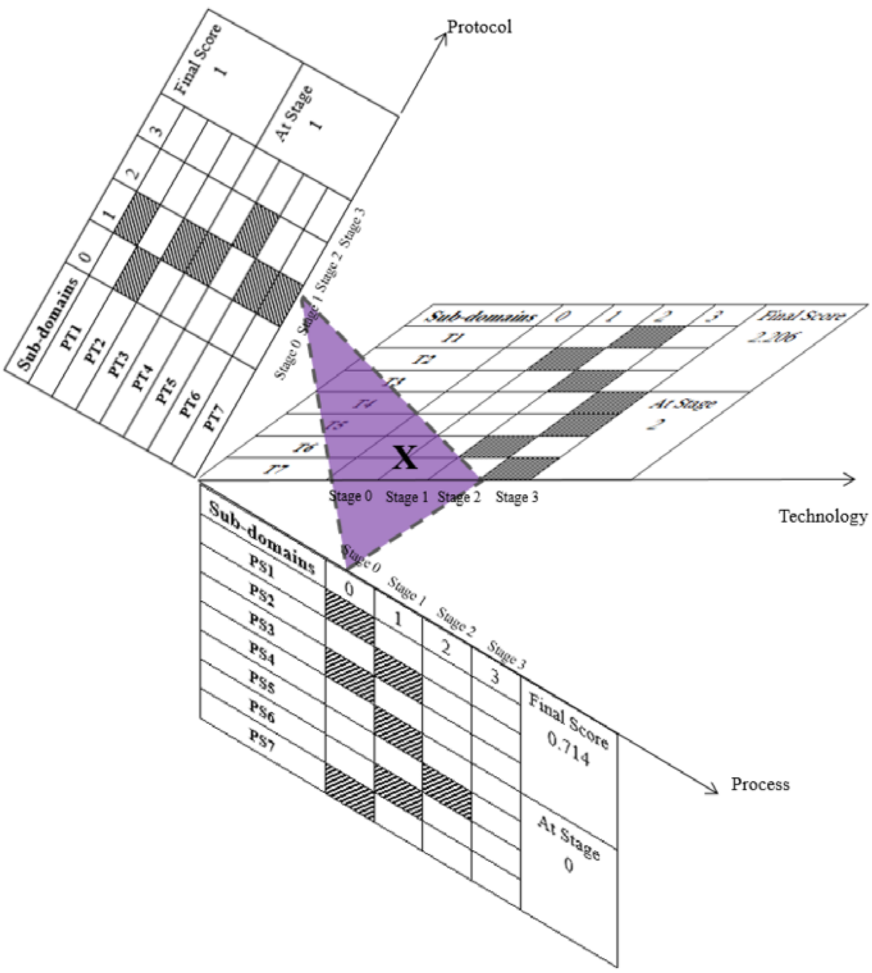

Fig. 1 Illustration of MBMM (Adapted from Liang et al. [2016])

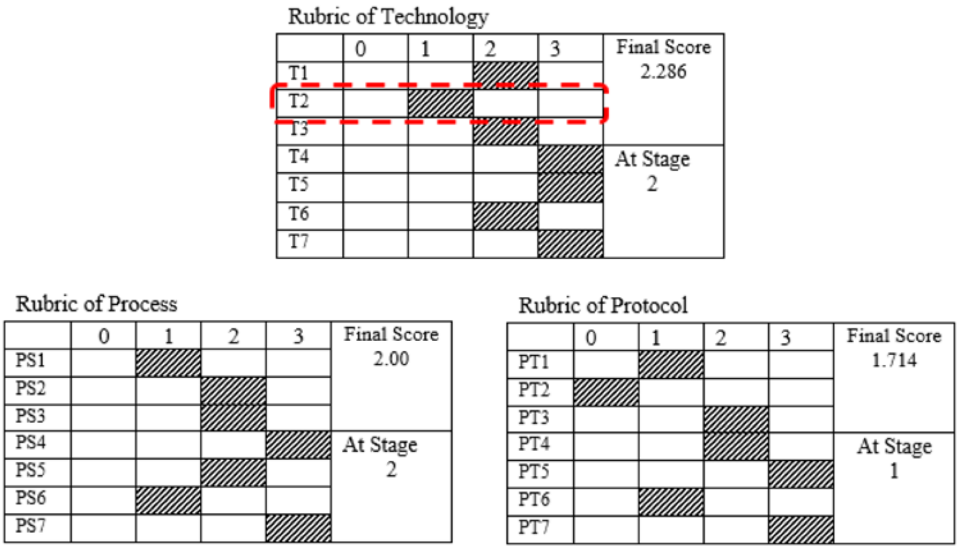

Fig. 2 Illustration of BIM maturity measurement by using MBMM

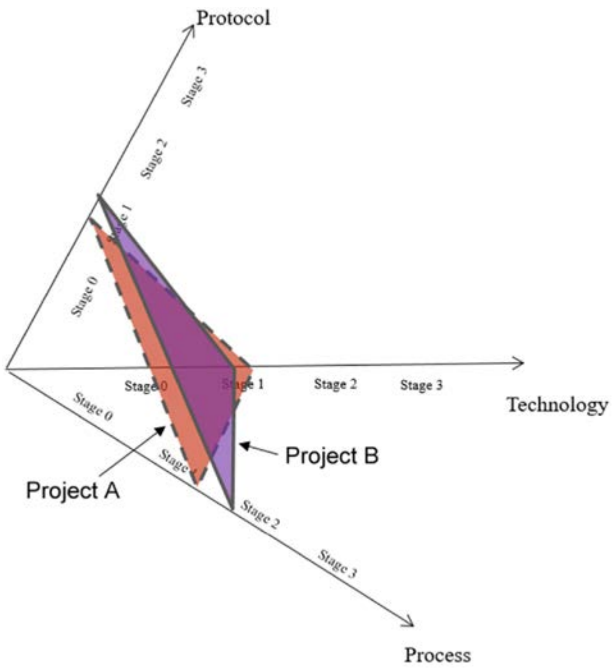

Fig. 3 BIM maturities of Projects A and B

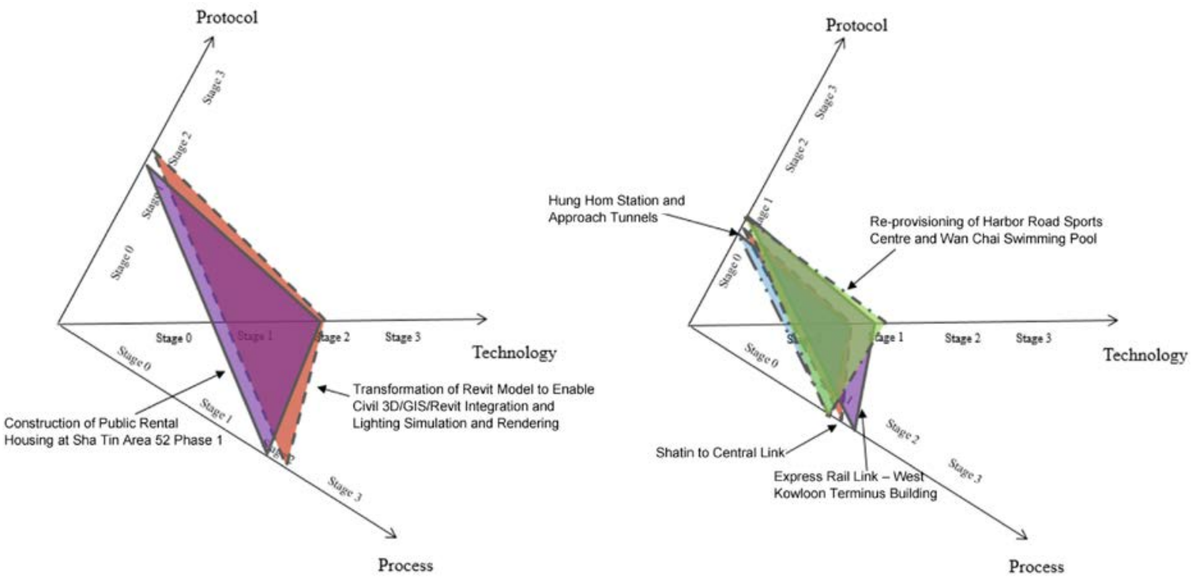

Fig. 4 BIM maturities of Organisations C and D

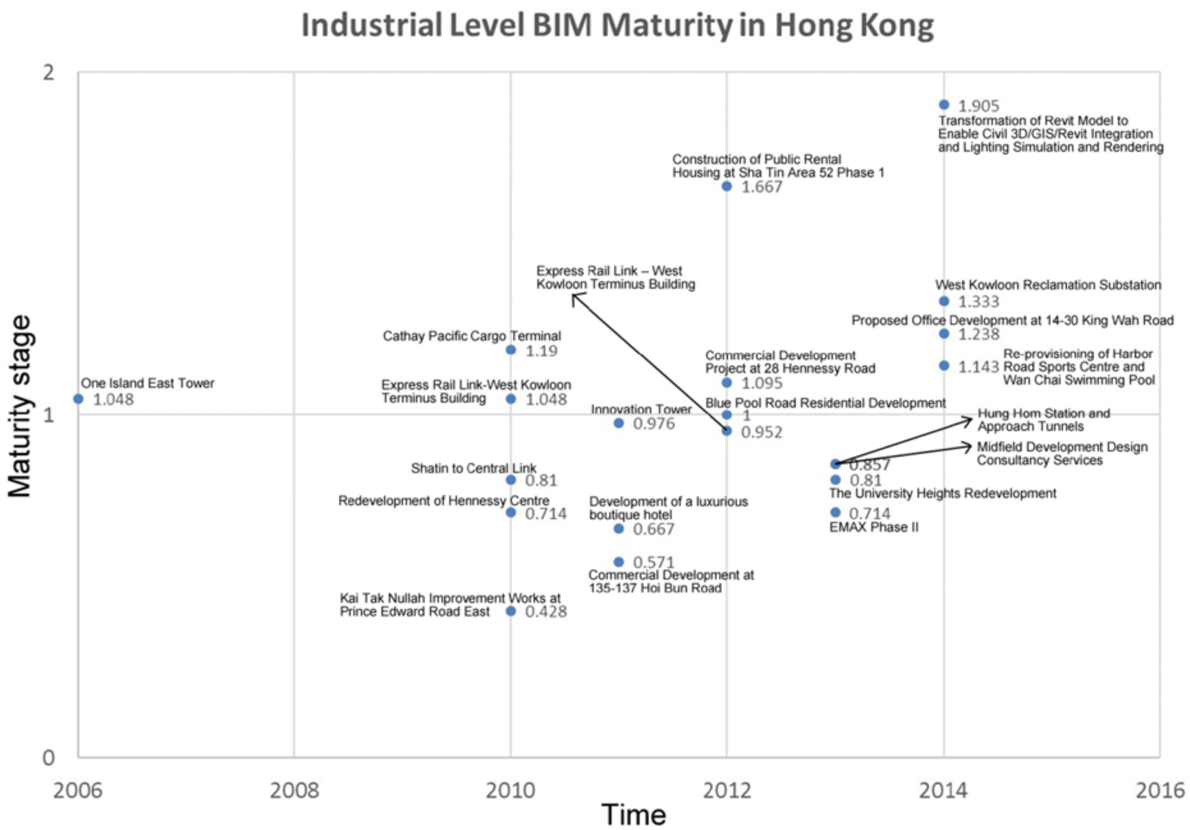

Fig. 5 Scatter plot of industry-level BIM maturity in Hong Kong