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# OVERVIEW OF BIM MATURITY MEASUREMENT TOOLS

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EDITOR: Turk Ž.

***Chengke Wu, M.D.;***
***Faculty of Construction Management and Real Estate, Chongqing University;***
***404835780@qq.com***

***Bo Xu, Associate Professor;***
***Faculty of Construction Management and Real Estate, Chongqing University;***
***358379785@qq.com***

***Chao Mao; Associate Professor;***
***Faculty of Construction Management and Real Estate, Chongqing University;***
***876099898@qq.com***

***Xiao Li; M.D.;***
***department of building and real estate, The Hong Kong Polytechnic University;***
***shell.x.li@connect.polyu.hk***

***SUMMARY:*** *Building Information Modelling has experienced rapid development in recent years. Recognized the numerous benefits, various organizations and stakeholders have begun to implement BIM. Contrary to the extensive application, successful implementation requires a thorough understanding of current situation of BIM operations as well as effective, advanced, and high-performing measurements. Despite the existing studies of BIM maturity measurement tools, there is no comprehensive review yet, resulting in confusions faced by BIM users that need to conduct such evaluations. This study exhaustively reviews nine mainstream BIM measurement tools developed in the past years, shedding light on their distinct features. According to the findings, no universal applicable tool exists and each tool has unique emphasis, strengths and weaknesses, matching different users. Besides, some patterns of measuring scope, measures selections and evaluation methods along the development of these tools are also identified. Therefore, this study could not only help BIM users to choose appropriate tools based on their unique demands, but also serve as reference for developments of new tools in the future.*

***KEYWORDS:*** *BIM Maturity, Measurement Tools, Overview*

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# 1. INTRODUCTION

BIM is a favored topic in the architecture engineering and construction (AEC) industry (Succar, 2010). BIM has been developed for more than a decade, and its benefits are now widely recognized (He, 2010). The perceptions of the industry toward BIM have changed along with its development. Unlike simple modeling methods in the past, BIM is currently regarded as workflows based on Information Technologies (IT), which emphasize cooperation and communication and require support from all organizational levels (Succar, 2009). The challenges in implementing BIM have also shifted from overcoming technical difficulties to seamlessly integrating BIM into daily working processes and achieving continuous improvements (Zhao, 2011; Pan et al., 2012; He et al., 2012; Li et al., 2015; Kekana et al., 2014).

To address these challenges, BIM users, namely, organizations at industry level and stakeholders at project level, should first evaluate the current conditions in BIM implementation to identify appropriate improvement paths that best match the characteristics of users (CIC, 2012, Lehtonen, 2001; Luu et al., 2008; Pillai et al., 2002). To meet the demands, several tools have been developed to measure BIM maturities. Despite the increasing number of measurement tools, research evaluating BIM maturity remains in its infancy (Dib et al., 2012), and industries have yet to establish standards for developing such tools. Tools are developed separately, featuring unique advantages but suffering from specific drawbacks. As a result, selecting a tool for evaluation is confusing for BIM users.

On the one hand, detailed reviews, which indicate the strengths, weaknesses, and other features of mainstream tools, help BIM users to select tools that meet their demands and conditions. On the other hand, these reviews can be used in developing new tools by providing valuable experiences. The problem is studies contributing such detailed reviews are few.

To bridge this research gap, this study thoroughly reviews nine BIM maturity measurement tools. The study presents three key findings:

- The nine tools can be categorized into two major classes, namely, tools for internal evaluation within organizations and those for evaluating stakeholders in projects.
- With own characteristics, strengths, and weaknesses, each tool suits users of different types; thus, a single and optimal tool for all users does not exist.
- The developments of these tools exhibit patterns in terms of measuring scope, measures selection and classification and evaluation methods, which provide experiences for developing new tools.

The study offers two contributions.

- Specific features of each tool are identified and analyzed, which serve as a basis for further research on BIM maturity evaluations.
- The findings provide references for the tool selection of BIM users as well as suggestions for future tool developments.

The article is organized as follows. Section 2 introduces current studies on BIM maturity measurements. Section 3 describes the methodologies adopted in this study. Section 4 provides a general review of the nine measurement tools. Section 5 includes comprehensive comparisons and describes the distinct features, strengths, and weaknesses of each tool. Section 6 discusses the findings and provides suggestions for tool selection and future tool developments. Section 7 concludes the study.

# 2. LITERATURE REVIEW

Dozens of BIM maturity measurement tools are available (Giel, 2014). Rather than identifying the features of these tools, previous studies focused on the development of tools, including creation of measurement frameworks, design and selection of measures, determination of evaluation approaches, validations, and optimizations.

Tools are usually developed based on separated research; thus, generally acceptable approaches in building the integral framework of tools are inexistent, particularly in terms of the classification of measures and the scope of measurement. Tools exhibit varying classification structures to accommodate indicators or measures because of the lack of established standards. For example, BIM Maturity Matrix (BIM MM) follows the same classification mode of its own preceded studies, which defined three BIM fields, namely, technology, process, and policy (Succar, 2012). By contrast, Owner's BIM CAT, which consists of three divisions and 12 sub-divisions, is developed through literature reviews and the opinions of experts (Giel and Issa, 2014). The scope of measurement also varies significantly; from specific evaluations limited to certain BIM fields to extensive measurements aiming to cover all aspects of BIM. Framework flexibility, which allows the adjustment of measures according to the attributes and demands of users, is only considered in a few tools (Succar, 2009). Nevertheless, some ideas share common features. For example, maturity levels in most tools are based on measurement models in traditional construction, project management, and the IT industry, such as People Capability Maturity Model, Project Management Process Maturity Model, and Standardized Process Improvement for Construction Enterprises (Khoshgoftar et al., 2009; Kwak et al., 2002; Hutchinson et al., 1999).

Delphi method is the most common method in the primary design of measures and determinations of weights. A significant knowledge gaps exist when problems in this area are investigated, and quantitative methods are not feasible because of inadequate pilot projects and cases; thus, Delphi method is a useful alternative (Skulmoski et al., 2007). Three rounds of Delphi seminars by more than eight experts are recommended (Hallowell and Gambatese, 2010).

For evaluation and scoring, some tools adopt single evaluation approach, such as scales, multiple-choice questionnaires, or blank fillings; others combine multiple approaches and integrate qualitative methods, such as open-ended questions (Kam et al., 2013; Kam et al., 2014). Weighted summation is the most common approach to calculate the aggregate BIM maturity score of all tools.

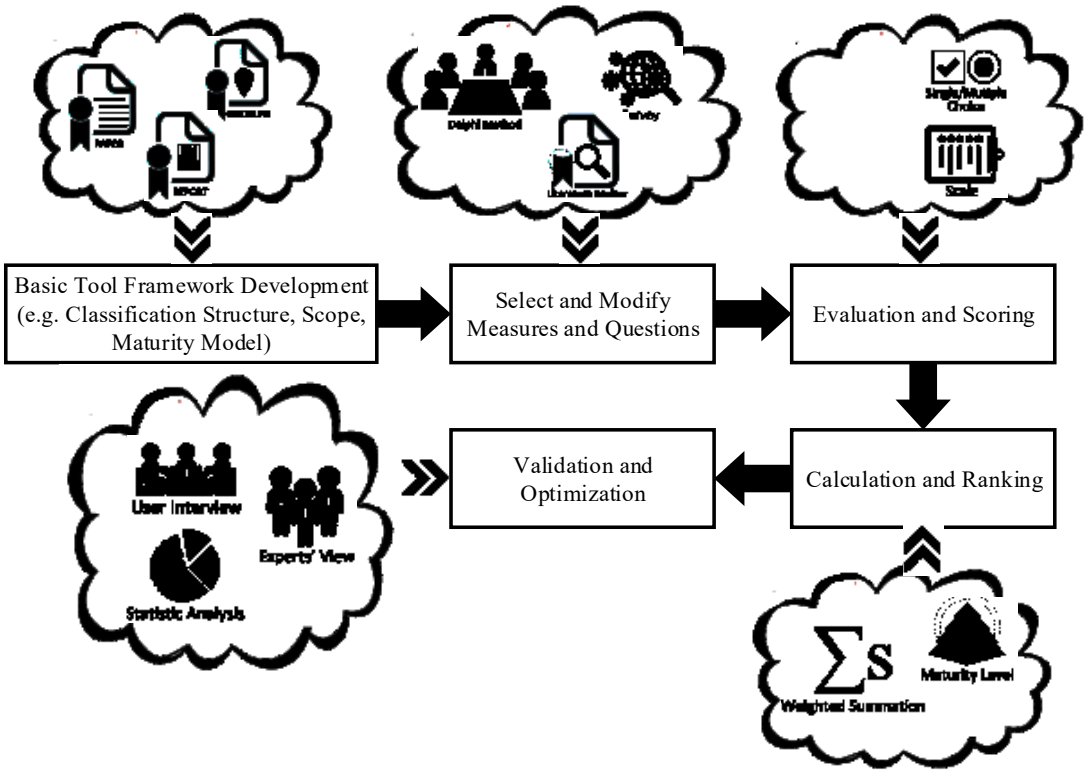



*FIG. 1: Summarization of measurement tool developments*

Both qualitative and quantitative methods are applied for validation and optimization. The former includes investigations on user satisfaction by conducting surveys and obtaining suggestions through interviews; the

latter refers to statistical analysis tools, such as Pearson's Correlation and Kendall's Tau (Agresti et al., 2010). Tools are tested in pilot projects through which measures are added, deleted, or refined and corresponding weights are adjusted. Other tools investigate variability and independence of measures to distinguish their capabilities, identify latent variables, and conduct cluster analysis to further improve classifications (Shannon, 1948; Zeleny et al., 1982; Greco et al., 2001; Bartholomew et al., 2011; Anderberg et al., 1988). Fig. 1 summarizes the development of the measurement tools.

Several overviews were already conducted on existing BIM maturity measurement tools (Giel, 2014; Dakhil et al., 2015; Marshall et al., 2010; Geil and Issa, 2013). However, these overviews only provide preliminary information, which neither comprehensively reveal the features of tools nor provide basis for tool selection or development. Hence, this study reviews, compares, and analyzes nine dominant tools in detail to improve research on this field.

## 3. METHODOLOGY

The research began with identifying the tools to be analyzed; a selection principle is necessary to determine representative samples. The selected tools must meet the following requirements:

- well-recognized by the industry;
- available literature on the tool that provides detailed information;
- developed and supported by reputable research;
- contains distinct features that are crucial in tool selection or may be exhibited in future tools.

Websites or introductory materials of each tool were reviewed, and available scientific papers and reports published by the development teams were examined to obtain appropriate information and data (Hwang and Zhao, 2015). Nine tools were selected: NBIMS Capability Maturity Model (NBIMS CMM), IU BIM Proficiency Index, BIM Maturity Matrix (BIM MM), BIM Quick Scan, Characterization Framework, Organizational BIM Assessment Profile, VDC Scorecard, Owner's BIM CAT, and BIM Cloud Score (BIMCS).

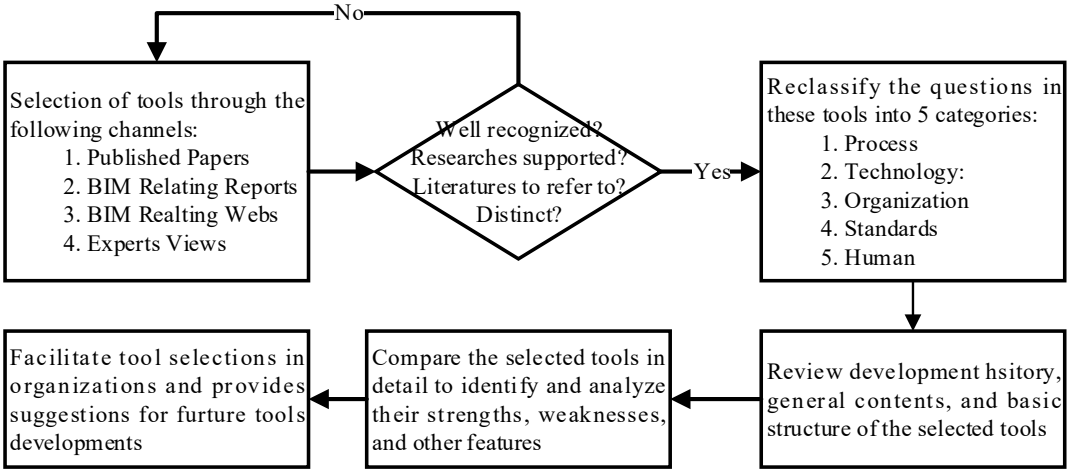



*FIG. 2: Summary of research flow*

The measures in these tools are classified differently, and thus, these measures must be reorganized for clear and consistent comparisons and analyses. Based on previous research (Giel and Issa, 2013; Succar, 2009) and opinions of experts, the measures of BIM maturity were classified into five categories, namely, Process, Technology, Organization, Standard and Human (Stakeholders). Process category assesses the establishment, management, and documentation processes of BIM-related works, deliveries, and interactions. Technology category evaluates the proficiencies of BIM functions and the qualities of relevant software, hardware, and deliverables. Organization category focuses on organizational BIM planning, including objectives, strategies,

and leadership supports. Human (Stakeholder) category addresses issues related to the capabilities, mentalities, and trainings of BIM staff. Finally, Standard category measures the implementations of standards, guidelines, specifications, and contracts. This classification structure is a typical example; other methods are available to classify the measures. Fig. 2 presents the research flow.

## 4. OVERVIEW OF TOOLS

This section provides an introduction of the selected tools following the development sequence, which serves as a foundation for comprehensive comparisons.

The first BIM maturity measurement tool is NBIMS CMM, proposed by the National Institute of Building Science in 2007 as part of its famous National BIM Standard. The model evaluates BIM implementation in 11 areas using a 10-level scale (NBIMS, 2007; Giel, 2014). The final score of BIM maturity is calculated by the weighted summation of all areas. The score is mapped to a maturity model with five levels to indicate the maturity degree the BIM user achieves. However, the weights of measures can be adjusted by users according to their own needs, which dramatically reduce the objectivity of this tool.

Indiana University developed IU BIM Proficiency Index two years later. This tool is created using Excel spreadsheet, which is composed of 8 areas, 32 measures, and 5 maturity levels (CIC, 2012). Unlike NIBMS CMM, each measure has the same weight in IU BIM Proficiency Index. To evaluate BIM implementation, a score between zero and one is assigned to each measure. Zero indicates the non-existence of corresponding BIM functions, whereas one specifies that functions are fully applied (Indiana University, 2009).

Although NBIMS CMM and IU BIM Proficiency Index are the bases for following tools, they are usually criticized because of high subjectivity, limited measurement scope in technical aspects, and inadequate reliability and consistency (Suucar, 2009). BIM MM was developed in 2009 to overcome these deficiencies. Based on established theories (Suucar, 2010), BIM MM provides comprehensive explanations for each measure to minimize inconsistencies and expands the measuring scope to cover non-technical aspects of BIM (Giel and Issa, 2013). BIM MM contains three main areas and adopts a five-level scale to conduct measurements. However, the number of measures is subjective to an innovative granularity system, which will be elaborated further. Considering the lack of information on BIM MM at a high level of granularity, only granularity at Level 2 is included, comprising 12 and 36 measures. The total BIM maturity level is calculated by averaging the scores of all measures.

BIM Quick Scan was launched in the Netherlands in 2011, which consists of four main areas and 44 measures that are organized in the form of a multiple-choice questionnaire (Sebastian and Berlo, 2010). The selection of measures and framework formation are based on Delphi method of five rounds (Berlo et al., 2012). The scoring approach is a weighted summation. BIM Quick Scan has two versions, namely, free online self-scan and chargeable certified scan, which is conducted by consultants. These consultants provide professional advice for both measurement outcomes and potential improvements. Practical BIM maturity benchmarking system is first established using this tool. The system is a collection of hundreds of data samples. Based on the system, BIM market conditions in the Netherlands and even in Europe are revealed, and the tool can be optimized through continuous feedbacks.

Some tools also developed during that time exhibit large-scale imitations, lacking distinct features and thus are excluded from the study. However, Characterization Framework, which was proposed in a doctoral thesis in 2011, opened new opportunities for BIM maturity measurements. Although the classification of Characterization Framework, which is composed of three main areas, 14 sub-divisions, and 56 measures (Gao, 2011), is similar with other tools, it characterizes evaluation schemes. The framework introduces quantitative blank-filling and open-ended questions to complement conventional scale or multiple-choice approaches. Furthermore, Delphi, complex statistical analysis, and face-to-face user interviews are conducted simultaneously for validation and optimization, which is also a distinctive contribution of the framework.

Inspired by Characterization Framework, VDC Scorecard was developed in 2012 by Stanford University to conduct methodological, adaptive, quantifiable, holistic, and practical assessment (Kam, 2013). VDC Scorecard includes 4 main areas, 10 divisions, and 74 measures. The tool has several distinct features, such as the establishment of confidence level, which analyzes input data and quantitative measurements of the degree of

objective compliances. VDC Scorecard is also a benchmarking tool where the answers of each measure will be assessed against the industry norm and converted into a five-level percentile ranking to indicate the maturity level of BIM in comparison with other users.

BIM in the O&M phase has begun. Pennsylvania State University published a guideline of key components and steps that facility owners need to integrate in their businesses, which include the BIM assessment profile. The assessment profile is composed of 6 areas, 20 measures, and 5 maturity levels to evaluate the BIM maturity of facility owners (CIC, 2012). By utilizing the tool and guideline, facility owners can understand current BIM maturity levels and identify correct paths to initiate or improve BIM implementations.

Owner's BIM CAT, which was developed in 2013, is another tool that regards owners as major users. The tool features 3 main measuring divisions, 12 sub-divisions, and 66 measures. Owner's BIM CAT is selected because of the extensive measuring scope, which covers almost all aspects of BIM applications with a life cycle view (Azzouze et al., 2015).

BIMCS, which contains six major measuring aspects and 19 quantitative measures, was developed in 2014 to particularly assess the maturity level of BIM modeling techniques (Du, 2014). When BIMCS is utilized, accurate data are required and relating processes, including data collection, evaluation and scores weighted summation, are all automated by utilizing clouding computing and pre-installed software. The system can self-optimize using multiple mathematical tests.

Although the review scope is not exhaustive and some existing tools are excluded in the study, the selected tools are the most distinct and representative ones, which are all based on established research. Moreover, majority of the tools have been more or less validated through various methods, which relatively guarantees effectiveness and reliability. The contents of this section are summarized in Fig 3.

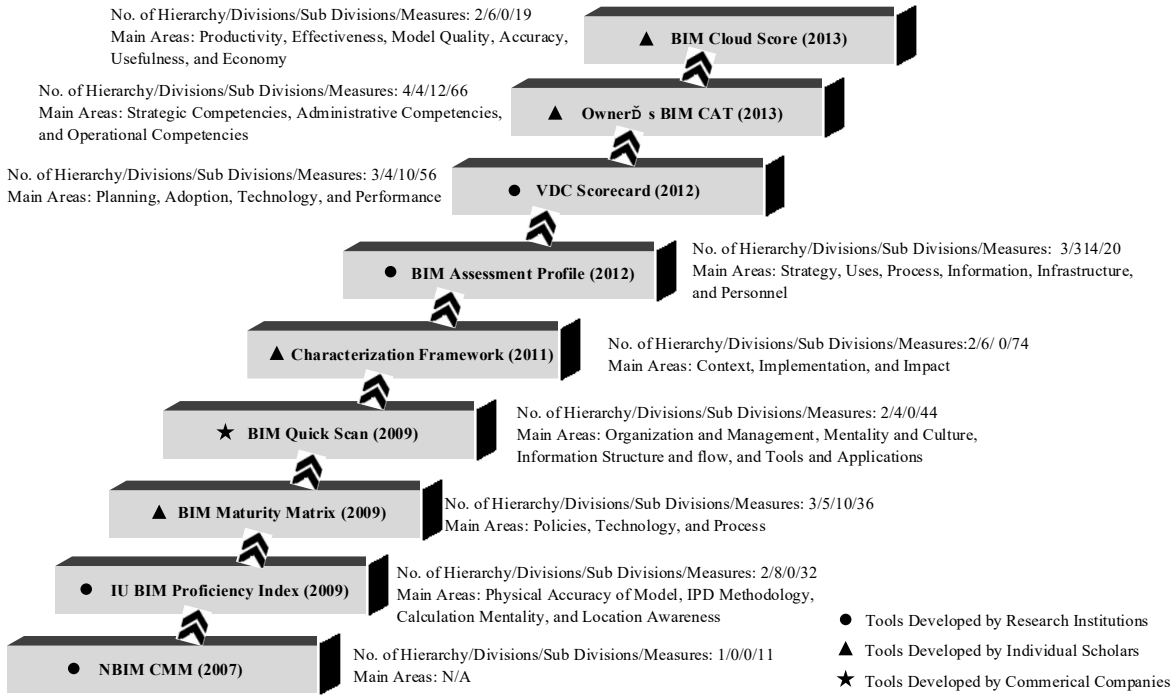



*FIG. 3: Summary of development history of BIM maturity measurement tools*

## 5. COMPARISONS ON QUESTIONS, FRAMEWORK, AND MECHANISMS

Individual questions, frameworks, and evaluation mechanisms are the basic components to develop a measurement tool. Comparisons among the nine measurement tools are conducted following three steps:

- compare questions to reveal measuring emphasis;

- investigate frameworks to understand static structures;
- shed light on evaluation mechanisms by analyzing related processes

The definition of "question" in this section slightly differs from the definition of "measure" described above because one measure may contain several questions.

## 5.1 Review of Questions

### 5.1.1 Number and Quantification of Questions

Questions are the fundamental components of measurements. VDC Scorecard contains 96 questions, which is the highest among those of other tools, followed by Owner's BIM CAT (66) and Characterization Framework (56), which indicates that adopting these tools may be difficult and resource-exhaustive. By contrast, NBIMS CMM and BIMCS include less than 20 questions, which show that these tools are easy to use. IU BIM Proficiency Index, BIM MM (Level 2), BIM Quick Scan, and BIM Assessment Profile have 32, 36, 44, and 30 questions, respectively, which feature a medium difficulty level of measurement.

Quantification degree determines the data required. Thus, quantification degree is another important indicator of measuring difficulty. Measurements in the four latter developed tools are more or less quantified. BIM Quick Scan has only three quantitative questions, whereas VDC Scorecard and Characterization Framework include 57 and 34 quantitative questions, respectively. Thus, these tools are more complex than the previously described tools, which conform to earlier findings. All questions in BIMCS are quantitative. Although only 19 questions are included, the implementation of BIMCS entails extensive effort.

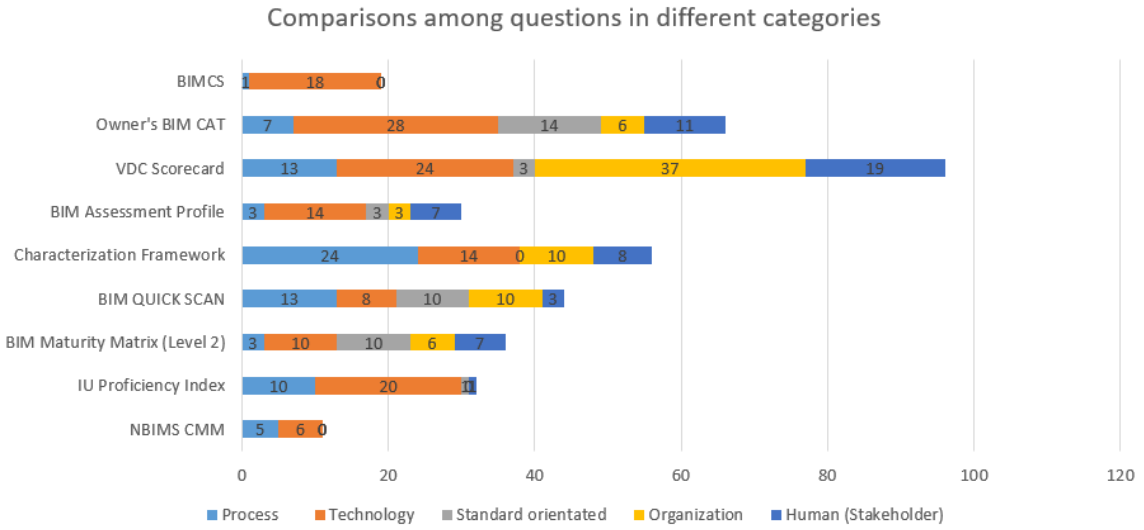



*FIG. 4: Comparisons of emphasis of different tools*

Although the nine tools are developed to measure BIM maturity, these tools focus on different aspects. Fig. 4 demonstrates the distribution of questions of the nine tools according to the uniform classification developed earlier. Most tools are detailed in certain aspects of BIM. BIMCS highlights the technical aspects of BIM. VDC Scorecard and Characterization Framework focus on the value of BIM maturity at the organizational level and in working processes, respectively. However, the distribution of questions in BIM MM (Level 2) is relatively more even. Measurements on technical issues commonly account for a large portion whereas the maturity of implementation of BIM standards is less discussed.

However, neither the number of questions and quantification degree nor rudimentary the comparison from a macro perspective are insufficient to reveal the features of a measurement tool. Thus, the 9 tools are compared category by category with specific analysis focusing on individual and evident characteristics.

### 5.1.2 Major Measuring Aspects in Process Category

Process maturity measurements focus on the modeling process and information flow of BIM and the coordination among different disciplines and documentation processes. Tools are usually selected to evaluate several types of these processes instead of all of the processes. Tables 1 and 6 summarize the typical questions and major measuring aspects of process assessment in the nine tools, respectively.

*TABLE 1: Typical questions of Process related measurements*

| Tool's Name | Typical Questions/ Measures |
|---|---|
| NBIMS CMM | Degree of IFC supporting IPD process, Degree of change management processes, Degree of BIM integration in business, Timeliness of responses, Life cycle views |
| IU BIM Proficiency Index | Design collision detection process, Introduction of structural and MEP model, IPD methodology innovations, Processes in coordination meetings, Generations of post bid model documentation |
| BIM Maturity Matrix (Level 2) | To what degree knowledge infrastructure is developed, to what degree model production process and service are defined and well managed |
| BIM Quick Scan | Use/Re-use of information from partners? Where in the process do you use BIM? Are the information flows within your company described? |
| BIM Assessment Profile | Degree of internal and external BIM processes documentation and management, Existence of transition plans for each operating unit |
| VDC Scorecard | Response to RFI on time when it is made within how many calendar days? Efficiency of VDC/BIM meetings, which of the following process gained expected benefits? |
| BIMCS | Number and efficiency of meetings to enhance LOD |
| Owner's BIM CAT | Most questions are similar with those mentioned above |
| Characterization Framework | Most questions are similar with those mentioned above; plus Explain the actual impacts on working processes with BIM |

Table 6 indicates that all tools highlight the coordination among different disciplines or stakeholders considering that interoperability is regarded as the core of BIM. Except for coordination issues, the variance of measuring emphasis on BIM-related processes is significant. For example, IU BIM Proficiency Index only addresses the technical aspect, which includes the processes of modeling and information generation in this case. NBIMS CMM and BIM Quick Scan emphasize both technical and managerial aspects, like processes of information collection and generation for the former and management processes of information flow and knowledge sharing for the latter. VDC Scorecard and Characterization Framework feature the evaluations of the actual performances in BIM-related processes and the resultant benefits and impacts on current processes, respectively. Owner's BIM CAT and Characterization Framework conduct comprehensive measurements by expanding their measuring scopes and including detailed questions.

BIM Assessment Profile is rather distinct in this category because it highlights the ability of transitioning from primary processes in which BIM is not adopted or in the initial stage to mature processes after BIM has been successfully implemented, requiring specific goals and milestones. Thus, users can develop a clear roadmap of BIM implementations.

### 5.1.3 Major Measuring Aspects in Technology Category

All tools measure technical maturity of BIM but with different concentrations. The typical questions and major measuring aspects of technique assessment are summarized in Tables 2 and 7, respectively.

*TABLE 2: Typical questions of Techniques related measurements*

| Tool | Typical Questions/ Measures |
|---|---|
| NBIMS CMM | To what degree the model is nD intelligent; to what degree model incorporate with spatial information and GIS; to what degree information is accurate based on ground truth |
| IU BIM Proficiency Index | To what degree model is geometrically correct; to what degree models reflect built environment and design intent; to what degree model produces correct quantity schedule |
| BIM Maturity Matrix (Level 2) | To what degree real-time network solution is achieved; to what degree software and BIM uses are in line with organizational strategies or plans; to what degree software and hardware are adequate and under control and monitoring |
| BIM Quick Scan | What is the semantic level of your BIM? For what applications do you use BIM? What is the reuse of BIM data? Do you use open standards to communicate? |
| BIM Assessment Profile | To what degree BIM data is received and used in O&M; to what degree BIM uses are adopted in O&M, To what degree BIM software selection match organizational plans |
| VDC Scorecard | What is the average information loss after model exchange? What is the most common format of model exchange? Select model-based analysis used, Contribution of BIM techniques to the users. |
| Characterization Framework | To what degree BIM models improve the accuracy of cost estimation; Demonstrate useful functionality of BIM software; Demonstrate types of model uses |
| Owner's BIM CAT | Most questions are similar with those mentioned above |
| BIMCS | Total number of modeling steps/total number of objects; Number that the model was accessed per duration; Number of discrepancies between each discipline's model; Model Size per SF of the building |

According to Table 7, BIM uses or functions, information accuracy, and data richness are the most common measuring aspects. VDC Scorecard and Characterization Framework highlight the quality of information exchange and integrate assessments of actual performances and effects on products of BIM. BIM MM and VDC Scorecard innovatively consider information security and access.

Earlier tools tend to evaluate specific BIM uses or functions, such as collision detections in IU BIM Proficiency Index and spatial capability with GIS in NBIMS CMM. The possible rational is that only small number of BIM uses existed when the tools were developed. Thus, assessing these fields became critical to indicate BIM maturity.

Another noticeable difference lies in the definition of the technical maturity of BIM. Various tools are biased because measurements will improve when more BIM uses or functions are adopted. By contrast, BIM MM and BIM Assessment Profile emphasize the degree to which BIM implementations are consistent with organizational strategies, budgets, and plans, which may be realistic and flexible and avoids wastage merely to achieve high evaluation outcomes.

### 5.1.4 Major Measuring Aspects in Organization Category

Not all tools measure the maturity of the organizational issues of BIM. The measuring emphasis and typical questions are presented in Tables 3 and 8.

*TABLE 3: Typical questions of Organization related measurements*

| Tool's Name | Typical Questions/ Measures |
|---|---|
| BIM Maturity Matrix (Level 2) | To what degree BIM vision is established and commonly communicated; to what degree BIM implementation are integrated with organizational strategies; How the leadership treat BIM; to what degree BIM budget is accord with techniques |
| BIM Quick Scan | Is there complete company support for BIM (at all levels of the organization)? Is the term "BIM" a part of the vision and strategy? Is it clear what your organization wants to achieve with BIM? |
| BIM Assessment Profile | To what degree clear organizational missions and visions are established and communicated; to what degree management supports are provided; to what degree BIM objectives or missions are in line with strategies |
| VDC Scorecard | List most important VDC/BIM objectives; how many objectives are quantifiable? How often objectives are tracked? To what degree objectives are achieved based on actual performance data |
| Characterization Framework | Cost of managing BIM; To what degree BIM vision is established; What impact does BIM bring on businesses of the user |
| Owner's BIM CAT | Most questions are similar with those mentioned above |

All tools that address organizational issues assess the existence of BIM goals or vision statements because these aspects are fundamental to implement innovations within an organization. Some tools, such as BIM Assessment Profile and Owner's BIM CAT further distinguish objectives, goals, and vision and mission statements and conduct measurements separately. The remaining tools simplify the concepts into one or two measures, which may cause confusions when more than one tool are adopted. For instance, if a user established specific BIM objectives according to VDC Scorecard but does not develop macro organizational BIM vision statements required by BIM Assessment Profile, the evaluation results will likely differ.

In this category, VDC Scorecard and Characterization Framework stand out. VDC scorecard assigns specific and quantifiable targets for each established objective. For example, the objective of saving cost can be achieved through targets, such as reducing change order rates. Actual performances are recorded based on these targets, and objective compliances are calculated. Therefore, unlike one-off assessments, VDC Scorecard develops feedback loops, which encourage users to establish goals and achieve them. Characterization Framework assesses the positive and negative effects of BIM on organizational performances, which stimulate users to identify and rectify problems in time.

Other tools, except for the two tools mentioned above, emphasize the importance of support from management levels, in terms of budget allocation and R&D efforts. BIM Quick Scan and BIM MM value the attitudes of leadership towards BIM, whereas BIM MM and BIM Assessment Profile emphasize that established objectives should match organizational strategies.

### 5.1.4 Major Measuring Aspects in Human (Stakeholder) Category

Six of the nine tools measure personnel arrangements of BIM or the capabilities and involvements of stakeholders, as indicated in Tables 4 and 9.

VDC Scorecard and Characterization Framework evaluate the maturity BIM in projects. Thus, these tools mainly measure stakeholder-related issues, whereas the other tools concentrate on personnel arrangements within organizations. Characterization Framework in this category only evaluates the existing skills and experiences of stakeholders and disregards training and psychological aspects. Thus, possessed abilities outweigh the provision of BIM trainings for stakeholders in the tool.

*TABLE 4: Typical questions of Human related measurements*

| Tool's Name | Typical Questions/ Measures |
|---|---|
| BIM Maturity Matrix (Level 2) | To what degree BIM responsibilities and roles are defined; to what degree staff is capable of BIM; to what degree training or education are provided |
| BIM Quick Scan | Are there BIM Champions within organization? Do you provide for structured training of staff? Do your employees enjoy working with BIM? What is, on average, the BIM practical experience level of your employees |
| BIM Assessment Profile | To what degree BIM responsibilities and roles are defined; to what degree training or education are provided |
| VDC Scorecard | How satisfied are the stakeholders with the results of BIM? What's the stakeholder's attitude towards BIM? Have designated BIM Champion? What's the BIM skill of project team member? |
| Characterization Framework | Number of individuals using BIM; Number of individuals building BIM; Number of Stakeholders initiating BIM efforts; |
| Owner's BIM CAT | To what degree hiring, evaluation and training practices are planned and implemented; to what degree BIM responsibilities and roles are defined |

Duty arrangements are universally important. However, most related measures lack specific definitions or descriptions for these duties and overemphasize the role of BIM champion. One exception is the assessment profile of BIM, which introduce four major types of BIM personnel, namely, BIM champion, BIM sponsor, BIM lead of individual units, and BIM operator. These aspects provide basis for developing specific and functional personnel arrangements from management to operational levels.

The skills and experiences of BIM staff comprise another critical measure, which is evaluated in all tools other than BIM Assessment Profile. BIM MM highlights this aspect and developed a model called BIM Competency Index to particularly measure individual BIM capabilities (Sccuar et al., 2013). However, BIM Competency Index is not as well-recognized as BIM MM and it is similar with the "Human" division in BIM MM with a high granularity, and as such, it is excluded from the study.

Some tools also consider the mentality issues of staff or stakeholders. VDC Scorecard and BIM Quick Scan measure the satisfaction and enjoyment of employees when they work with BIM. BIM Assessment Profile and Owner's BIM CAT evaluate change readiness. These evaluations are crucial because working stresses triggered by introducing innovations can significantly influence productivity (Leung et al., 2015). Thus, selecting BIM uses with proper complexities is important to stimulate productions while avoiding obstructions.

**5.1.5 Major Measuring Aspects in Standard Category**

Six selected tools include questions related to standard category. Tables 5 and 10 summarize the typical questions and measuring emphasis.

The tools do not focus on the evaluations of BIM standards implementations as much as other categories, which are reflected by the low number of questions in this field. VDC Scorecard even entrusts guideline selection to users by just requiring them to check the boxes to demonstrate the guidelines they decide to adopt.

However, BIM MM (Level 2) is an exemption. Other tools only require general demonstrations of adopted standards or merely measure certain types of guidelines, such as information or model breakdown standards and information exchange standards in BIM Assessment Profile and implementation of BIM Execution Plan (BEP) in IU BIM Proficiency Index. BIM MM (Level 2) expands the measuring scope and develops specific measures to further include issues of contracts, benchmarking procedures, and quality control plans. BIM MM emphasizes the match degree between the implementation of BIM standards and organizational strategies,

which encourage the adoption of standards that meet the long-term plans of an organization.

*TABLE 5: Typical questions of BIM Standards related measurements*

| Tool's Name | Typical Questions/ Measures |
|---|---|
| IU BIM Proficiency Index | To what degree BEP is properly created and implemented |
| BIM Maturity Matrix (Level 2) | To what degree detailed guidelines are available; to what degree 3D models are managed under detailed standards; to what degree an agreement is established to manage BIM intelligent property |
| BIM Quick Scan | Do you use open standards to communicate with external partners? Do you prefer a specific kind of contract with your partners? Are there quality controls in place for BIM? |
| BIM Assessment Profile | To what degree standards are used to determine O&M data needs; to what degree standards are used for model breakdown structure |
| VDC Scorecard | Select contents covered by BIM guidelines' scope; Have you established any BIM guidelines or BEP and list them (if any) |
| Owner's BIM CAT | To what degree detailed working guidelines are available; to what degree BEP templates are implemented; to what degree delivery procedures are well defined and disseminated |

## 5.2 Review of Framework

Framework is a static structure that organizes questions, defines the measuring scope, and determines the integral characteristics of tools. The following contents introduce and compare the frameworks of the nine tools.

### 5.2.1 Classification and Hierarchy

Unlike NBIMS CMM, which is the earliest developed tool where all 11 questions are in the same hierarchy, other tools all have two to four hierarchies and corresponding classifications. NBIMS CMM has only a small number of measures, which are limited to technical aspects. Thus, further classification is unnecessary. When the number of questions increases, appropriate allocation of hierarchies and development of classifications are indispensable to produce additional indicators without causing unexpected overlaps and errors.

However, the number of hierarchies, as well as the divisions and sub-divisions in each hierarchy, varies in tools. As a result, divisions or sub-divisions with the same title may comprise different measures. For instance, the measure "Existence of BIM related roles" is classified under the "Organization and Management" division in BIM Quick Scan. However, this measure is under the "Human Resource" sub-division in BIM MM. These differences easily lead to confusions, particularly when more than one tool are adopted. If one tool is used for measurement and another is utilized for verification, different outcomes are obtained within the same measuring aspects.

### 5.2.2 Flexibility

Flexible tools can be adjusted to match BIM users of different scales, BIM maturity levels, and core business types. However, most tools either do not address flexibility issues or bypass the problems to target certain users, such as BIM Assessment Profile for facility owners. In addition, tools that combine quantitative and qualitative questions while adopt multiple evaluation methods tend to be more flexible.

BIM MM is quite distinct, which characterizes its granularity system as filters of measures. BIM MM includes four granularity levels. Each level contains different numbers of questions for various assessment objectives,

which range from basic situation discovery in low levels to accurate auditing in high levels. However, BIM MM has limitations. The number of questions and measuring complexity increase with granularity level while the lack of user guides reduces the applicability of the tool, which necessitate appropriate assistance is necessary. Besides, BIM MM cannot adjust measures according to other attributes except scale, such as business types.

#### 5.2.3 Measuring Scope

The measuring scope of tools exhibits an inverted U-shape. The measuring scopes in the two earliest tools are limited to the technical aspects of BIM. BIM MM and recent tools keep expanding measuring scopes by detailing certain aspects, such as BIM Assessment Profile, which elaborates organizational objective settings and personnel arrangements, or by integrating non-technical aspects, such as BIM Quick Scan, which introduces mentality issues. Owner's BIM CAT reached a vertex in terms of measuring scope by extensively gathering questions in previously developed tools, after which some tools began to narrow the scopes to increase concentration. Typical examples include BIMCS, which measures BIM models and modeling qualities, and BIM Competency Index, which assesses the capabilities of BIM staff. However, the latter is not included in the study.

#### 5.2.4 Supporting Research and Guidelines

Various questions in measurements are unfamiliar to users with less experience in BIM. Although there are descriptions of questions in each tool, understanding the meanings of these questions are still difficult due to lack of detailed user guidelines. Therefore most tools suffer from low usability. Evaluators can misunderstand meanings of questions or have contradicting views, e.g. one may easily find difficulty in distinguishing "Expanded Data Set" and "Enhanced Data Set" in NBIMS CMM without proper directions, which directly affects the consistency and validity of outcomes. To address the problems, research teams of some tools, such as BIM Quick Scan, provide commercial versions, which are conducted by professional consultants. However, users may be reluctant to invest in these tools.

BIM Assessment Profile stands out because of the useful guideline, which includes comprehensive descriptions of questions and suggestions for BIM implementation and improvements as well. For instance, in measuring BIM uses, BIM Assessment Profile not only asks to select implemented uses but also recommends several O&M BIM uses with detailed introductions, including the major functions and requirements of implementation. As a result, users can consistently assess the maturity of BIM while determining necessary uses. During the transition process towards high BIM maturity, the guideline cooperates with the measurement tool to provide directions to develop proper roadmaps. Hence, owners will find BIM Assessment Profile helpful and manageable.

### 5.3 Review of Evaluation Mechanisms

When static structures are determined, dynamic evaluation mechanisms must be also analyzed to reveal other characteristics of tools, which are summarized in Table 11.

*TABLE 6: Major measuring aspects of Process related measurements*

| Measuring Aspects of Process \ Tools | NBIM CMM | IU BIM Proficiency Index | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | BIM Cloud Score | Owner's BIM CAT | BIM Characterization Framework |
|---|---|---|---|---|---|---|---|---|---|
| 1. Change Orders Management Process through BIM | ● | | | | | ● | | ● | ● |
| 2. Co-ordination and Handover Processes between Different Project Phases | ● | | | ● | | ● | | ● | ● |
| 3. Interaction Co-ordination and Communication Processes among Multiple Disciplines or Stakeholders | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| 4. Information Collection and Response Processes and Information Flow Management | ● | | | ● | | ● | | ● | ● |
| 5. Information Generation and Documentation Processes (e.g. Quantity Take-offs, Week Schedules, etc.) | | ● | | ● | | | | ● | ● |
| 6. Delivery Processes of BIM Relating Products and Services | ● | | ● | | | | | ● | ● |
| 7. Knowledge Sharing Processes | | | ● | | | | | ● | |
| 8. Reuse Procedures of BIM Related Information and Data | | | | ● | | | | ● | |
| 9. Documentations of Actually Gained Benefits or Impacts on Working Processes through Applying BIM | | | | | | | | | ● |
| 10. Records of Actual Performance and the Contribution of BIM Related Processes to Objectives Compliances | | | | | | ● | | | |
| 11. Target BIM Relating Processes and Developments of Plans of Transitions towards the Targets | | | | | ● | | | | |

*TABLE 7: Major measuring aspects of Technique related measurements*

| Measuring Aspects of Technique \ Tools | NBIMS CMM | IU BIM Proficiency Index | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | BIM Cloud Score | Owner's BIM CAT | BIM Characterization Framework |
|---|---|---|---|---|---|---|---|---|---|
| 1. Data and Information Richness (rich data on both graphical and non-graphical information and life cycle information uses) | ● | ● | | ● | ● | ● | ● | ● | ● |
| 2. Information or Data Accuracy in BIM Models | ● | ● | | | | | ● | ● | ● |
| 3. Location or Spatial Capabilities and Awareness | ● | ● | | | | | | ● | ● |
| 4. Model Based Calculations and Analysis | ● | ● | | | | ● | | ● | ● |
| 5. BIM Functions Adoption and Software Selections | | | ● | ● | ● | | | ● | ● |
| 6. BIM Relating Hardware Implemented (e.g. Equipment Purchasing and Relating Physical Space Building) | | | ● | | ● | | | ● | |
| 7. BIM Networking Establishments (e.g. intranets, extranets, and platforms, etc.) | ● | | ● | | | | | ● | |
| 8. Data Exchange Qualities, Formats and Information Loss | | | | ● | | ● | | ● | ● |
| 9. Information Security and Access Control | | | ● | | | ● | | | |
| 10. Modelling Cost-Effectiveness and Efficiencies | | | | | | | ● | | ● |
| 11. Records of Actual Performance and the Contribution of BIM Related Techniques to Objectives Compliances | | | | | | ● | | | |
| 12. Documentations of the Gained Benefits or Impacts of BIM Techniques on Productions | | | | | | | | | ● |
| 13. Match Degree between Techniques and Strategies | | | ● | | ● | | | | |

*TABLE 8: Major measuring aspects of Organization related measurements*

| Measuring Aspects of Organization \ Tools | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | Owner's BIM CAT | BIM Characterization Framework |
|---|---|---|---|---|---|---|
| 1. BIM Visions, Goals and Strategies at Organization Level | ● | ● | ● | | ● | ● |
| 2. BIM Missions and Objectives at Operation Level | | | ● | ● | ● | |
| 3. Senior Management Supports (e.g. Personnel, Finance) | ● | ● | ● | ● | ● | ● |
| 4. Attitude of Management and Leadership towards BIM | ● | | | ● | ● | |
| 5. Research and Development Efforts (R&D) | ● | | | | ● | ● |
| 6. Objectives Establishments and Degree of Compliances | | | | ● | | |
| 7. Actual Impacts of BIM on Organizations | | | | | | ● |

*TABLE 9: Major measuring aspects of Human related measurements*

| Measuring Aspects of Human (Organization Personnel or Stakeholders) \ Tools | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | Owner's BIM CAT | BIM Characterization Framework |
|---|---|---|---|---|---|---|
| 1. BIM Related Staff Experiences, Skills and Knowledge of BIM Staff/Stakeholders | ● | ● | | ● | ● | ● |
| 2. Arrangement of BIM Related Duties and Roles | ● | | ● | ● | ● | |
| 3. BIM Related Training and Education | ● | ● | ● | ● | ● | |
| 4. Existence and Functions of BIM Champion/Leader | | ● | ● | ● | ● | |
| 5. Awareness, Attitudes, Enjoyments and involvements of Employees/Stakeholders towards BIM | | ● | | ● | ● | |
| 6. Change Readiness among Employees/Stakeholders | | | ● | | ● | |

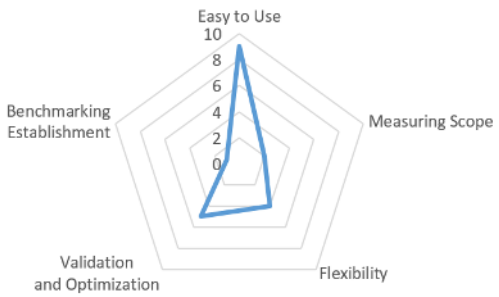
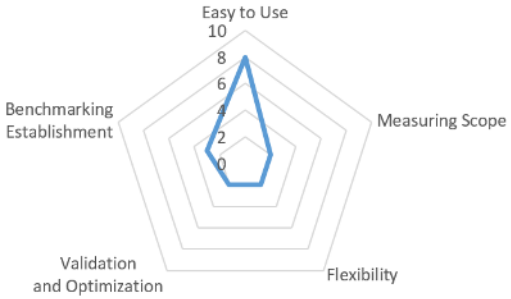
*TABLE 10: Major measuring aspects of BIM Standards related measurements*

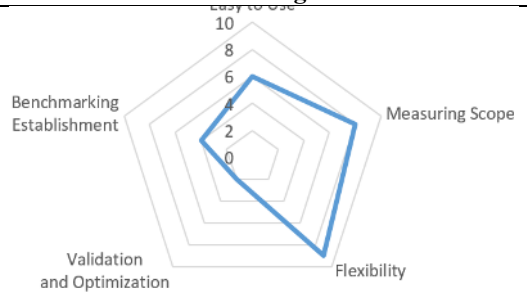
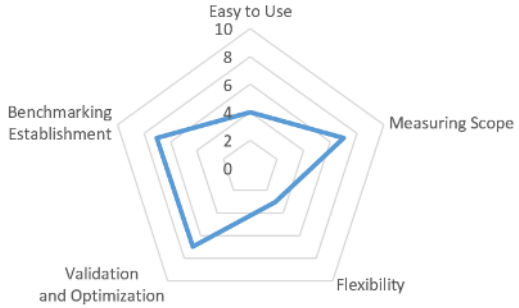
| Measuring Aspects of Human (Organization Personnel or Stakeholders) \ Tools | IU BIM Proficiency Index | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | Owner's BIM CAT |
|---|---|---|---|---|---|---|
| 1. Development of BIM Execution Plan (BEP) or Adoptions of BEP Templates | ● | | | ● | ● | ● |
| 2. Development of Contracts of BIM Related Rewards and Risks Allocations | | ● | ● | | | |
| 3. Guidelines to Implement and Improve BIM in Current Businesses | | | | ● | | ● |
| 4. General Procedures, Protocols and Regulations of Routine BIM Related Works | | ● | | | | ● |
| 5. Data Exchange Standards | | | | ● | | |
| 6. BIM Products and Services Delivery Guidelines | | ● | | | | |
| 7. Guidelines of BIM Related Information Needs and Information/Model Breakdown Structure | | | ● | ● | | |
| 8. BIM Training and Education Standards | | | | | | |
| 9. Quality Control Plans | | ● | ● | | | ● |
| 10. BIM Benchmarking Procedures | | ● | | | | |
| 11. Match Degree between Implemented Standards and Status and Goals of the Organization | | ● | | | | |

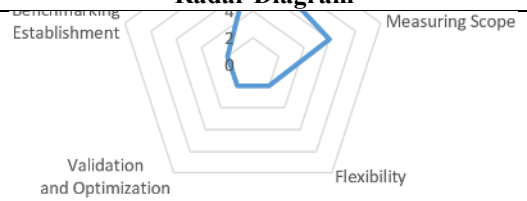
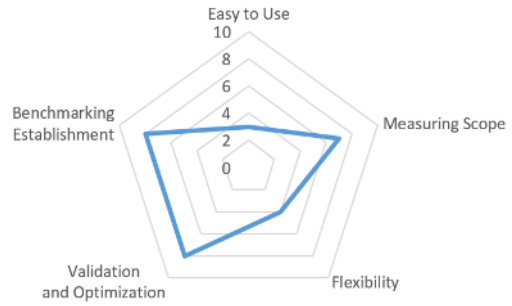
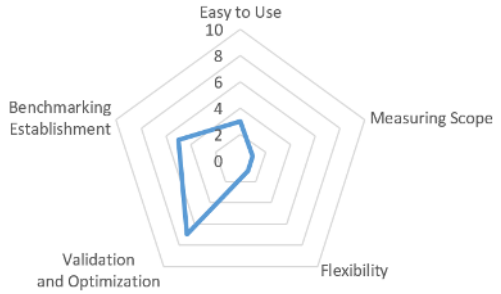
*TABLE 11: Summary of relating evaluation mechanisms*

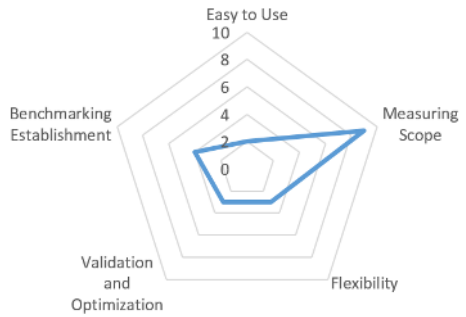
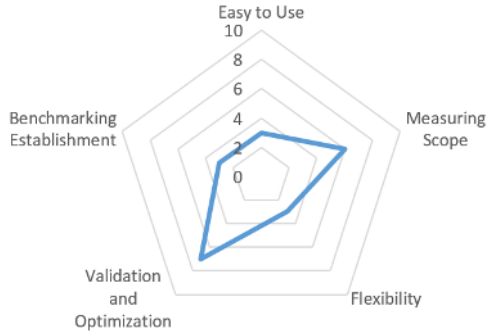
| Evaluation Approaches \ Tools | | NBIMS CMM | IU BIM Proficiency Index | BIM Maturity Matrix | BIM Quick Scan | BIM Assessment Profile | VDC Scorecard | BIM Cloud Score | Owner's BIM CAT | BIM Characterization Framework |
|---|---|---|---|---|---|---|---|---|---|---|
| Data Collection Methods | Interview | ● | ● | ● | | ● | | | ● | ● |
| | Offline Questionnaire | ● | ● | ● | | ● | | | ● | ● |
| | Online Questionnaire | | | | ● | | ● | | | |
| | Consultant Evaluation | | | | ● | | | | | |
| | Automated Collection | | | | | | | ● | | |
| Evaluation Methods | Scale (5 or 10 level) | ● | | ● | | ● | ● | | ● | ● |
| | Self-scoring from 0 - 1 | | ● | | | | | | | |
| | Multiple Choices | | | | ● | | ● | | | |
| | Quantitative Blank Fillings | | | | | | ● | ● | | ● |
| | Open Ended Questions | | | | | | ● | | | ● |
| Validation Methods | Pilot Project Testing | ● | | | ● | | ● | ● | ● | ● |
| | Users Interviews | ● | | | | | ● | | | ● |
| | Experts Consulting | ● | | | ● | | ● | | ● | ● |
| | Multiple Types of Statistical Tests | | | | ● | | ● | ● | | ● |
| | Not Introduced Clearly | | ● | ● | | ● | | | | |
| Optimization Aspects | Questions Weights | ● | | | ● | | | ● | | ● |
| | Question Descriptions | | | | | | ● | | | ● |
| | Required Scores to Reach Certain Maturity | ● | | | | | | | | |
| | Add/Delete Questions | | | | ● | | ● | ● | | ● |
| | Reform Classifications | | | | | | | ● | | |
| | Not Introduced Clearly | | ● | ● | | ● | | | ● | |

*TABLE 12: Main strengths of each tool*

| Tool | Radar Diagram | Main Strengths | Main Weaknesses |
|---|---|---|---|
| NBIMS CMM |  | The number of questions is quite small;<br>Structure is the simplest among all tools (there is only 1 layer of classification structure) ;<br>Has some flexibility since the weights of questions can be adjusted by the user;<br>The easiest tool to implement;<br>Conducts field tests and practical data collections for tool validation | Quantification of evaluation is low;<br>No user guides and question descriptions are rough;<br>Limited scope to BIM technical aspects;<br>Single evaluation method and is subjective;<br>No benchmarking functions;<br>Validation and optimization are relatively qualitative and subjective |
| IU BIM Proficiency Index |  | The number of questions is relatively small;<br>The structure is simple;<br>Easy to implement;<br>Proposes a benchmarking concept | Quantification of evaluation is low;<br>All measures has same weight, no distinction;<br>No user guides and question descriptions are rough;<br>Limited scope to BIM technical aspects;<br>Single evaluation method and is highly subjective;<br>Low flexibility;<br>Lacks field tests, empirical studies and practical data collections for validation and optimization |
| BIM Maturity Matrix | | Questions descriptions are relatively detailed;<br>Structure is highly flexible and adjustable for different users' aims; | Quantification of evaluation is low;<br>Number of questions and complexity increase along with the granularity level; |

| Tool | Radar Diagram | Main Strengths | Main Weaknesses |
|---|---|---|---|
| |  | Covers multiple aspects of BIM and the measuring scope is extensive;<br>Easy to implement;<br>Emphasizes the matching between BIM and organizational strategies and resources | No user guides and question descriptions are rough at high granularity level;<br>Single evaluation method and is subjective;<br>Lacks field tests, empirical studies and practical data collections for validation and optimization;<br>No benchmarking functions |
| BIM Quick Scan |  | Quantification of evaluation is relatively high;<br>Emphasizes mentality issues and measuring scope is relatively extensive;<br>Has some flexibility due to adoption of multiple evaluation methods and question types;<br>Has chargeable consultant service to conduct measurements and provides suggestions;<br>Conducts field tests and practical data collections for tool validation;<br>Benchmarking system is practically developed | No user guides and question descriptions are rough;<br>Relatively more difficult to implement and the results of self-scans are less reliable without consultant services;<br>Consultant service is chargeable, requiring extra investments |
| BIM Assessment Profile | | Has a detailed user guideline measurements;<br>Measuring scope is relatively extensive;<br>Emphasizes the matching between BIM and organizational strategies and resources; | Quantification of evaluation is low;<br>Single evaluation method and is subjective;<br>Lacks field tests, empirical studies and practical data collections for validation and optimization; |

| Tool | Radar Diagram | Main Strengths | Main Weaknesses |
|---|---|---|---|
| |  | Highlights and helps to develop organizational BIM transitions and improvements paths;<br>Easy to understand and implement | No benchmarking functions;<br>Specially designed for facility owner, low universal applicability and low flexibility |
| VDC Scorecard |  | Quantification of evaluation is high;<br>Highlights the compliances of objectives<br>The flexibility is relatively higher due to multiple question types and methods for evaluation, validation and optimization;<br>Measuring scope is relatively extensive;<br>Develops a confidence level system to increase data reliability;<br>Benchmarking system is practically developed | Number of questions is quite large;<br>Questions are projects-orientated, may not suitable for organizations without adjustments;<br>No user guides, implementation is difficult, time and resources exhaustive;<br>High requirement for data in terms of timeliness and quality |
| BIM Cloud Score |  | Quantification of evaluation is high;<br>The number of questions is small;<br>Automatically collects data, increasing data reliability by reducing human interventions;<br>Runs validation and optimization consistently and automatically;<br>Develops a practical benchmarking framework | No user guides and implementation is difficult;<br>Limited scope to BIM technical aspects;<br>Single evaluation method and is pure quantitative;<br>Low flexibility;<br>Requires extra maintenance for clouding server and pre-installed software;<br>Lacks field tests, empirical studies and practical data collections for validation and optimization |

| Tool | Radar Diagram | Main Strengths | Main Weaknesses |
|---|---|---|---|
| Owner's BIM CAT |  | Measuring scope is the most extensive among all tools;<br>Has some flexibility due to adoption of multiple evaluation methods and question types;<br>Refers to previous tools and takes use of their research achievements | Number of questions is quite large;<br>No user guides and question descriptions are rough;<br>The classification structure is very complex;<br>Difficult to implement, especially to ensure the completeness given the large number of questions;<br>Overlaps between questions in different fields;<br>Lacks field tests, empirical studies and practical data collections for validation and optimization |
| BIM Characterization Framework |  | Quantification of evaluation is high;<br>Question descriptions are relatively detailed;<br>The flexibility is relatively higher due to multiple question types and methods for evaluation, validation and optimization;<br>Emphasizes the actual impacts of BIM on users; | Questions are projects-orientated, may not suitable for organizations without adjustments;<br>No user guides, implementation is difficult, time and resources exhaustive;<br>High requirement for input data in terms of timeliness and quality;<br>Lacks measures for maturity of BIM standards; |

### 5.3.1 Methods of Evaluation and Scoring

The methods to evaluate each question vary. Tools employ different evaluation approaches, as summarized in the Table 11. Scale is the most common method which is used in all tools except IU BIM Proficiency Index, BIM Quick Scan, and BIMCS. IU BIM Proficiency Index directly asks evaluators to identify a score from zero to one in each measuring area. Thus, this tool is highly subjective. BIM Quick Scan, and BIMCS adopt multiple choice questionnaires and pure quantitative blank filling as evaluation approaches, respectively.

To overcome the low flexibility and comprehensiveness in adopting a single evaluation approach, several tools, such as VDC Scorecard, Characterization Framework , combine multiple approaches and include open-ended questions, such as “Reasons of iterations of BIM” and “List most important BIM objectives” to consider subjective opinions from people. Considering the diversity of evaluation approaches, regulations or algorithms that transform the answers of users to numeric scores are also critical for tool functionality. Fortunately, users only need to completely answer all questions in the selected tools and send them back through online interfaces or through e-mail. Supporting research teams will subsequently conduct background calculations and deliver results.

All tools adopt weighted summation as a method to calculate scores. A particular weight is assigned to each question and division to obtain the final result. The scores of questions are multiplied with the corresponding weights to produce the scores of divisions where these questions belong. The final result is calculated by adding the scores of divisions multiplied with the corresponding division weights.

### 5.3.2 Data Collection

To ensure the validity of measurements, particularly for quantitative questions, the approaches to collect data must be carefully considered. Most tools in the current study use traditional questionnaires to collect data for evaluation, validation, and optimization. However, BIMCS characterizes its automatic data collection method, where clients are required to first install certain software in their computers, which are also used for BIM modeling, to automatically extract information from BIM models and sent the data to a cloud service to run calculations.

Before the data are used in score calculations, a strict examination system should be established to test the reliability of data. Although various tools lack this system, VDC scorecard sets up a typical example, which establishes a criteria called “confidence level,” assesses seven core factors, including metrics like comprehensiveness, total duration of completion, number of stakeholders involved, to evaluate data reliability quantitatively and qualitatively. Data samples below a certain confidence level will be excluded from subsequent processes. Establishing this system is critical to produce objective measurement outcomes and benchmark developments, considering that only accurate data can correctly indicate market situations.

### 5.3.3 Benchmarking Procedures

Some tools only aim to achieve a certain level of BIM maturity to provide certifications while disregarding performance comparisons and mutual learning among users. For example, NBIMS CMM focuses on achieving the “Minimum BIM” instead of encouraging users to lead BIM implementation. Therefore, these tools are suitable for internal evaluations and not for benchmarking systems.

Six tools have benchmarking procedures, which enable users to compare outcomes with others and understand their positions of BIM maturity in the industry. IU BIM proficiency index first proposed a simple benchmarking concept by asking evaluators to determine the degree to which a user takes the lead in the industry of each measuring area. Despite BIM MM, BIMCS, and BIM Owner’s CAT consider benchmarking procedures as an important measure, the implementation and effectiveness of these systems remain unclear because of the lack of studies and practices. VDC Scorecard and BIM Quick Scan initiated extensive and practical benchmarking data collection to obtain benchmarking concepts in previous tools (the former collected 108 samples and the latter collected 130 certified scans). However, the benchmarking system of BIM maturity is not recognized worldwide.

### 5.3.4 Validation and Optimization

According to Table 11, the methods of validation and optimization in nearly half of the nine tools are vaguely introduced, which indicates that tool reliability and continuous improvements are inadequately considered. Moreover, existing validation methods are also highly qualitative. For example, NBIMS CMM adopts subjective user interviews for validation (Suremann et al., 2008). As a result, only the weights of questions and scores that are required in these tools to reach certain BIM maturity levels are refined, whereas the number and definitions of questions remain unchanged.

Recently developed tools adopt multiple statistical methods to test the significance and correlations of questions. If questions are highly correlated, the questions may be merged. If measures are poorly related to maturity, these measures are revisited. Based on the test results, both questions and the corresponding weights are adjusted. Additionally, the highly accurate data collected through pre-installed software enable BIMCS to run complex tests and further reform its classification.

## 6. DISCUSSION

Fig. 5 divides the nine tools into three dimensions, whereas in Table 12, strengths and weaknesses of tools are summarized and a radar diagram is drawn for each tool to demonstrate their features graphically according to the review. It is worth to note for simplicity, some previous contents are integrated into one dimension in the radar diagram. For instance, how "Easy to Use" of a tool is determined by the number of questions, complexity of classification structure, quantification degree, evaluation methods adopted, and existence of user guides; and "Flexibility" is determined by the ability of tools to match different user demands and the flexibility of questions. BIM users can select tools from several perspectives.

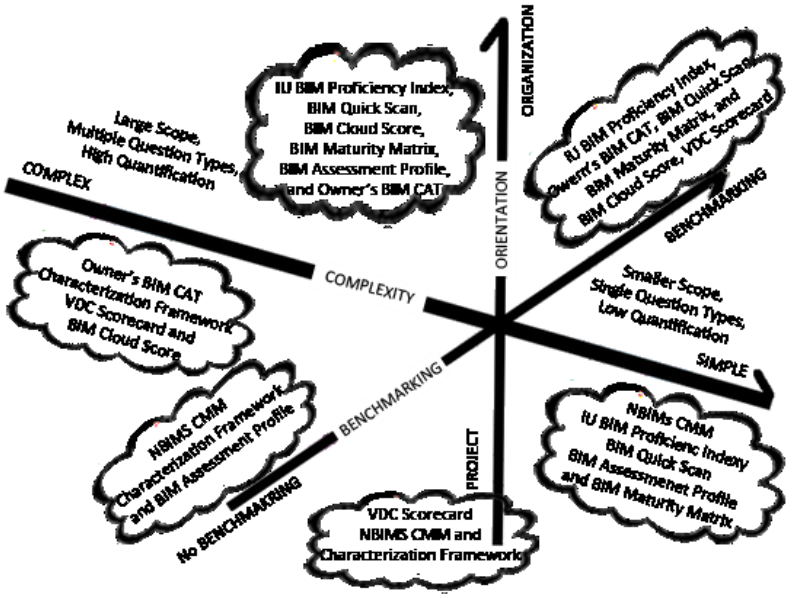



*FIG. 5: Dimensions of measurement tools*

## 6.1 Perspective of Measurement Orientation

The results of the review and previous findings (Giel and Issa, 2013) indicate that current tools can be divided into two groups, namely, project-orientated tools, which focus on measuring the BIM implementations of stakeholders in projects, such as VDC Scorecard, Characterization Framework, and NBIMS CMM, and organization-orientated tools, which highlight internal measurements within organizations. Thus, measurement targets must first be understood by users before selecting tools.

Although most questions in the three project-orientated tools are at project level, such as effectiveness of

interactions, coordination meetings, and benefits of stakeholders, they contain similar questions that are also included in organization-orientated tools, such as the quality of deliverables and adopted BIM software. Thus, if an organization plays a central role in projects where frequent multi-disciplinary interactions are required, such as a general contractor, using both tools is favorable and the outcomes from project-orientated tools can act as auxiliary indicators of BIM situations in organizations.

## 6.2 Perspective of Questions

Questions determine measuring emphasis and reflect the complexity, strengths, and weaknesses of tools to a certain extent. According to previous contents, BIM users can either select an intact single tool or partially use different tools.

The holistic complexity and the scope of questions in a selected tool must be considered. If BIM implementation is in its infancy stage, IU BIM Proficiency Index and NBIMS CMM are recommended for users. Despite their limitations, the two tools are easy to use in evaluating basic BIM functions and necessary processes to initiate BIM. However, other issues such as organization scales and business types cannot be ignored, as well as the increase of BIM experiences. For instance, if a BIM user is a small special sub-contractor, routine working processes and personnel are easy to document and manage, and the enterprise competency highly depends on BIM modeling qualities. BIMCS, which particularly measures BIM modeling without requiring information in managerial and personnel aspects, most effectively meets demands. By contrast, large entities, such as EPC contractors with complex hierarchies and multiple on-going projects, require comprehensive tools to identify current BIM performances. In this case, VDC Scorecard, Characterization Framework and Owner's BIM CAT may be applicable.

According to specific demands, users can extract certain measures from tools to maximize potential and avoid the drawbacks of individual tools as much as possible. For example, if a BIM user wants to evaluate whether BIM personnel arrangements are appropriate and identify future improvements, related contents in tools which present strengths in this field can be employed, such as BIM Assessment Profile. BIM MM at higher granularity level is recommended to evaluate the skills and experiences of staff or stakeholders. If a BIM user needs to measure the implementation of BIM standards, BIM MM and Owner's BIM CAT are recommended. VDC Scorecard and BIM Assessment Profile are the best tools to use to evaluate objective settings quantitatively and qualitatively, respectively. Characterization Framework can indicate the actual effects of BIM. Last but not least, if a BIM user wants to examine modeling and model qualities, BIMCS is a good option. Thus, users may obtain additional alternatives and selections are flexible. However, benchmarking procedures established in these tools are not applicable because measures are extracted from the different structures.

## 6.3 Perspective of Framework and Evaluation Mechanisms

BIM users must consider the features of frameworks and related evaluation mechanisms, aside from the design of questions.

To avoid confusions and errors caused by unstandardized classifications, users should select or develop uniform classifications for their own use before an industry-recognized standard is developed for classification and hierarchy. An example of constructing a new classification is described in Section 3.

Evaluation approaches significantly affect the resources required to complete measurements. Simple scales or multiple-choice questionnaires are cheap and easy to employ, but these approaches suffer from high subjectivity. On the other hand, without certain knowledge, experiences, and trainings, ordinary staff cannot simultaneously handle multiple approaches in complex tools to produce correct outcomes. Considering the diversity of evaluation approaches in recent tools, BIM users may either hire consultants to conduct BIM measurements or provide relevant trainings to their own employees.

Consistent benchmarking will contribute to BIM implementations in the entire industry because participants can compare the results of BIM maturity, learn from the best practices, and share experiences (Costa et al., 2006; Bendell et al., 1993; Barber, 2004; CDT, 2002). If BIM users desire to demystify their market positions of BIM maturity and learn from others, tools with valid benchmarking procedures must be prioritized, particularly those with strict data examinations and those that apply benchmarking system, such as VDC Scorecard.

## 6.4 Suggestions for New Tools

The findings of this study help BIM users to make informed decisions and serve as basis in developing new tools by providing experiences regarding question designs, framework creation, and related mechanisms.

First, determining a proper quantification degree is a major issue that new tools must carefully consider. Recently developed tools tend to include additional quantifiable questions. Quantification will increase measurement reliability. However, new tools must determine the aspects of BIM implementation that must be quantified to balance measurement complexity. Based on the experiences, quantifiable questions can be first allocated to assess modeling techniques, deliverable qualities, objective compliance, and interaction processes. Developing questions in these aspects is convenient because mature indexes and evaluation approaches have already existed. Furthermore, complexity can be controlled to a certain degree because of the relatively high data availability.

For the framework, new tools must consider measuring scope and supporting guidelines. The change of scope may remind development teams of new tools that expansions alone can lead to unacceptable complexity. By contrast, concentrating on particular aspects will more likely meet the specific requirements of users. Besides, BIM Assessment Profile is the only tool that provides specific guidelines. Thus, additional efforts are required to develop these supporting documents. In addition, new tools may either target certain types of BIM users based on attributes, such as core business and BIM experiences (Ku and Taiebat, 2011), or develop highly flexible frameworks referring to BIM MM.

Evaluation approaches and processes of validation and optimization must always be taken into account. Different evaluation approaches can complement each other. Therefore, diverse approaches are recommended for new tools, particularly in measuring non-technical aspects, where applying both quantitative and qualitative questions will produce more comprehensive results. Last but not least, new tools should focus on validations and optimizations and utilize advanced and automated techniques (Li and Deng, 2009; Mell and Grance, 2009) to design procedures to assess data reliability, quantitative validations, and continuous optimizations due to pertinent techniques are less challenging now.

# 7. CONCLUSION

This paper comprehensively reviews nine of the most typical BIM maturity measurement tools, including NBIMS Capability Maturity Model, IU BIM Proficiency Index, BIM Maturity Matrix, BIM Quick Scan, Characterization Framework, Organizational BIM Assessment Profile, VDC Scorecard, Owner's BIM CAT, and BIM Cloud Score. Their distinct features are identified through detailed comparisons and analysis. Thus, this research bridges the gap of a comprehensive review of such tools.

All the studied tools have their own characteristics in terms of question design, framework, and evaluation mechanisms. Several of them are quite easy to use but contain high subjectivity such as NBIMS CMM and IU BIM Proficiency Index; whereas others adopt complex methods for evaluation, validation and optimization and require actual and timely data, such as VDC Scorecard and BIM Cloud Score. Several present particularly strengths in certain aspects, such as BIM Cloud Score in measuring modelling techniques and BIM Assessment Profile in measuring objective settings and BIM personnel arrangements; whereas others conduct more evenly evaluations, such as BIM MM and Owner's BIM CAT. Several are highly flexible such as BIM MM; while others concentrate on certain user types, such as BIM Assessment Profile and Owner's BIM CAT. These characteristics significantly affect measuring emphasis, complexities, strengths, and weaknesses, which in turn determine the types of suitable users. This study acts as a reference in tool selections for BIM users that plan to implement or improve BIM implementations. Suggestions for new tool development are also provided based on the experiences of the nine tools in this study.

The major limitation of this study is that a detailed analysis of the attributes of different BIM users is not yet included. Thus, the ability to guide BIM users in the real world can still be largely improved. However, the primary purpose of this study is to thoroughly review and compare existing BIM maturity measurement tools, which BIM users can refer to, instead of developing practical guides. The goal has been achieved from this perspective, and the study findings are already beneficial for the leaders of users in determining which tool is suitable.

Given these limitations, future studies can concentrate on investigating the attributes of BIM users in terms of core business types, BIM experiences, and resource amounts. Practical tests that utilize existing tools and interviews with both leadership and normal BIM staff among the users will also be conducted. Hence, a more detailed guide to match BIM users and maturity measurement tools can be developed.

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