A FRAMEWORK FOR MEASURING BUILDING INFORMATION MODELING MATURITY BASED ON PERCEPTION OF PRACTITIONERS AND ACADEMICS OUTSIDE THE USA

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ABSTRACT

With the wide and quick adoption of Building Information Modeling (BIM) in the Architecture, Engineering, and Construction (AEC) industry, a benchmark is needed to evaluate and compare the BIM Maturity at the project level. Although there have been some efforts in proposing models for measuring BIM Maturity (BIMM), few empirical studies have been conducted to quantitatively develop and test the proposed framework. What is more, there is no quantitative research about BIMM based on the perception from BIM-related experts outside the USA. This research was conducted to fill these gaps and to develop a comprehensive and precise framework for measuring BIMM based on literature review and empirical analysis of perception of academic and industry BIM-related experts outside the USA. First, by reviewing previous maturity models about software development process, construction supply chain, virtual design and construction (VDC), and BIM, 27 indices were adopted for measuring BIMM. And then a survey based on the identified indices was conducted to BIM-related professional to gain their perception about the importance of each index in measuring BIM Maturity. Five underlying constructs of similar areas was then identified by analyzing the collected data by Principal Component Factor Analysis (PCFA), including Planning and Management of Process and Technology, Team Structure, Hardware, Process Definition, and Information Management. Though Process Definition ranked the first while Hardware ranked the last, the factor scores were quite close. It was therefore concluded that the focus of BIM has shifted from technical factor to the factors of information, process, and people, all of which were comparatively equally important for measuring BIMM. Finally, it was found that both the structure of the framework and the ranking of the factors were consistent with the related research efforts, which further confirmed the comprehension of the framework and the related results.

Keywords: Building Information Modeling (BIM), maturity, framework, project, Architecture, Engineering, and Construction (AEC).

1. INTRODUCTION

It was advocated that “BIM is not tomorrow’s vision; it is today’s reality” (Ashcraft 2008, p. 1). With the increased popularity and adoption of BIM, a benchmark is needed by the industry and its stakeholders to compare Apple to Apple (NIBS 2007). Some of the users claimed to be using BIM but only deployed a few copies of CAD, Revit, or Navis (Succar 2011). Some have been quick to embrace cutting-edge BIM-related technology regardless of the actual business practice and current capability of their technologies (Smith and Tardif, 2008). Others have developed a systematic and consistent plan to equip staff and infrastructure to integrate BIM into their business process. As you can tell, the BIM Maturity (BIMM), which refers to the extent to which the BIM is explicitly “defined, managed, integrated, and optimized”, is different across these firms/projects. The adoption of BIM is more than the update of the hardware or software infrastructure. It is a systematic approach to the lifecycle information related to a building (Smith and Tardif 2009). So how can individual, teams, projects, and organizations position BIM Maturity (BIMM) of their own and other's (Succar 2011), as well as to improve their BIMM? A rating framework is needed to compare the BIMM across the industry. Therefore, during August 2011 to May 2012, a study was carried out to fill this gap.

The research detailed in this paper is part of the project about Building Information Modeling Maturity, the goal of which was to develop a framework for measuring BIMM based on BIM-related experts from different countries. Considering that the sample may be heterogeneous because the perception of the experts in different countries may be interfered by the contextual factors like different regulations of construction industry, different adoption status of BIM, and different infrastructures, separate factor analyses should be performed (Hair et al. 2009). However, given the disproportional geographical distribution of BIM-related experts and disproportional responses from different countries, it was decided to divide the sample into two subsamples, the experts within and outside the USA. For the factor analysis for the subsample of the experts in the USA, please refer to the work of Chen et al. (2012). This paper reported the finding of the factor analysis based on the responses from BIM-related experts outside the USA. In the future study, the similarities and difference of the perceived frameworks by experts of the two subsamples will be compared and analyzed.

2. STAGE ONE: AREAS SYNTHESIS BASED ON LITERATURE REVIEW

2.1 Building Information Modeling

When one asks "What is BIM?" you can get 10 different answers from 10 different professionals (Fisk and Reynolds 2009). BIM is a multi-dimensional concept functioning differently to different professions. Architects use BIM as "the process and technology" (AIA 2008: A295, section 1.3.5) to create design and documents more efficiently and effectively, while engineers can assess and select optimal mechanical and electrical system for a building by BIM (Hardin 2009). Contractors use BIM as a computer software model to improve the process of design and construction (Hardin 2009), and improve decision making and facility delivery process (AGC 2006). Compared with other stakeholders, owners perceive "BIM as more of a collaborative process" (McGraw Hill 2008). BIM is defined as a "technology and process" to create, use, and coordinate information about a building project (FMI 2007). There are others definitions about BIM, including NIBS (2007) viewing BM as an improved life-cycle process and Eastman (2011) treating BIM as a "a modeling technology". Other than conflicting with each other, different definitions complement with each other and offer a different perspective to the understanding of BIM. Just like disco ball, you can see different colors from different perspectives; and different definitions are just different colors seen from different professionals of the discos ball of BIM. Depending on specific context, BIM can be used to represent either of these definitions. For the goal of this research, BIM was considered as a systematic approach to the lifecycle information related to a building by adopting Smith and Tardif's understanding of BIM (2009).

2.2 Building Information Modeling Maturity

Like the odometer for the measurement of car mileage, Leadership in Energy and Environmental Design (LEED) for the rating of building performance, Building Information Modeling Maturity (BIMM) refers to a rating system covering the key areas of an effective modeling process to deliver expected BIM product/service. The evaluation result of BIMM measures the extent to which BIM is explicitly "defined, managed, integrated, and optimized" (Succar 2010, p. 84).

The maturity model originated in the field of quality management with the premise that the quality of final product is "largely determined by the quality of the process used to develop and maintain it" (Paulk 1995, p. 8). One of the most well-known and widely-adopted maturity models is the Capability Maturity

Model (CMM), which was developed by the Software Engineering Institute (SEI) for software organizations to evaluate the software process to deliver final software product (Paulk 1995). Inspired by the success of CMM in the software industry, researchers in the construction industry began to investigated and proposed maturity models for different concepts in the construction industry, to name a few, like the Standardized Process Improvement for Construction Enterprise (SPICE) (Sarshar et al. 2000), the Project Management Process Maturity Model $(PM)^2$ (Kwak and Ibbs 2002), the Construction Supply Chain Maturity Model (CSCMM) (Vaidyanathan and Howell 2007). Among the maturity models in the construction industry, only four models claimed the ability to evaluate the maturity of BIM, including the Capability Maturity Model (CMM) by the National Institute of Building Science (NIBS) (2007), the BIM deliverable matrix by the Alliance for Construction Excellence (ACE) (2008), the BIM proficiency matrix by Indiana University (IU 2009), and Building Information Modeling Matrix Index (BIMMI) by Succar (2010). Except Succar's BIMMI, the other three models mainly concentrates on one aspect of BIM respectively. The NIBS's CMM focused on the management and the characteristics of the information within the BIM system (NIBS 2007), while BIM deliverable matrix targeted at the type and the delivery stage of BIM products (ACE 2008). Based on the limited information about IU's BIM proficiency matrix, this matrix was also perceived to emphasize on the BIM products by phases throughout the lifecycle of a building. Succar's BIMMI offered a comprehensive framework based on a comparatively exhaustive review of previous research effort, however, areas for information management are kind of weak.

Even there have been extensive research efforts, a comprehensive framework for BIM Maturity is still needed by individuals, groups, organizations, and even industry to define, measure, improve, and compare BIMM. For the goal of this research, the key areas within NIBS's CMM and Succar's BIMMI were combined and extracted to establish the initial pool for the BIMM framework. Here is the authors' rationale: First, it was argued that different projects may require different types of BIM products at different phases with different advance level, it was decided to target at the characteristics and quality of the information within the BIM products other than the specific type of BIM product. Therefore, the 11 areas of NIBS's CMM was adopted directly. Second, Succar's BIMMI covered the key areas of technology, process, and policy. Considering the redundancy of some items within the model and the strategic scale of this research project, 36 areas of BIMMI were extracted into 16 key areas. For a detailed comparison of the BIMM areas used in this study, the corresponding original areas used in NIBS's CMM and Succar's BIMMI, and similar areas explored in related research, please refer to the work of Chen et al. (2012). The definition for each area were listed immediately behind the question for the related area in Part III of the questionnaire in the Appendix.

3. STAGE TWO: IDENTIFICATION OF A MEASUREMENT MODEL OF BIMM

3.1 Questionnaire survey – Data Collection

In order to elicit BIM-related experts' perception about the framework for measuring BIMM, a questionnaire survey was conducted online through Qualtrics. Two questionnaires were designed separately for academic and industry experts. Both questionnaires included three main sections, including questions about demographic information, perception about each area on a seven-point Likert scale, and comments about the proposed framework. The questionnaire for the practitioners is identical to that for the academicians except the section of demographic information. Specifically, academicians were asked about their research areas and projects about BIM in the demographic section while practitioners were asked about their company profile and their direct working experience with BIM. To safeguard the quality of the responses, if the academic professional claimed that s/he did not take part in any BIM research/project, or was not familiar with BIM, her/his response was discarded. And if practitioners had been involved in less than two BIM-implemented project or had less than one-year direct working experience with BIM, their responses were not used as well.

The population included all academic and industry experts who were knowledgeable and experienced about BIM outside the USA. The sample included 205 academicians and 125 practitioners outside the USA. The academicians were identified from publications or reports about BIM and related models, from social networking site like Linkedin based on respondents' profile, and personal contact of the authors. And the practitioners were targeted at industry practitioners identified from Linkedin, members of Construction Industry Community of Practice in Project Management Institute, and industry authors of BIM-related publication.

During August 20th 2011 and February 29th 2012, 77 valid responses were received continuously. By filtering the valid responses based on the criteria mentioned above, 36 qualified responses from academicians were kept while 34 qualified responses from practitioners. The detail about the responses was listed in Table 1.

Table 1: Information about response from academicians and practitioners outside the USA

	Questionnaires Sent	Responses Received (%)	Valid Responses (%)	Qualified Responses (%)
Academicians	205	38 (18.54%)	37 (18.05%)	36 (17.56%)
Practitioners	125	49 (39.20%)	40 (32.00%)	34 (27.20%)
Total	330	87 (26.36%)	77 (23.33%)	70 21.21%)

3.2 Data analysis and interpretation

3.2.1 Ranking of the 27 Building Information Modeling Maturity Areas

The relative ranking of the 27 BIMM areas was listed in Table 2. Except the lowest score of Reward System, the mean-scores for the other 26 areas lied between 5.10 and 6.60. The closeness of the scores implied that these areas were perceived as quite the same level of importance by the respondents. There is little information the managers can extract from this ranking because even a small change of the score can result in a noticeable change in the ranking. In this situation, exploring the underlying constructs of these areas may better serve the managers' understanding and decision-making related to BIM investment or improvement.

Table 2: Relative importance ranking of 27 BIMM areas

BIMM Areas	Mean	STD	Ranking	BIMM Areas	Mean	STD	Ranking
Information accuracy	6.57	0.554	1	Applications	5.89	1.222	15
Interoperability	6.50	0.631	2	Specifications	5.88	0.796	16
Information delivery method	6.40	0.788	3	Risk management	5.83	1.014	17
Doc. & modelling standards	6.29	0.730	4	Proc. & Tech. Innov.	5.80	1.030	18
Information assurance	6.29	0.870	5	Role	5.71	1.045	19
Change management	6.14	0.785	6	Real-time data	5.66	0.883	20
Work flow	6.07	0.767	7	Competency profile	5.63	1.078	21
Senior leadership	6.07	1.108	8	Training delivery	5.49	1.196	22
Lifecycle process	6.04	0.806	9	Graphics	5.27	1.166	23
Quality control	6.01	0.993	10	Equipment	5.26	1.270	24
Training program	6.00	0.985	11	Geospatial capability	5.23	1.157	25
Data richness	5.99	0.876	12	Hardware upgrade	5.13	1.361	26
Strategic planning	5.96	1.109	13	Reward system	4.99	1.460	27
Standard operation process	5.91	0.887	14				

3.2.2 Measurement model of BIMM: Principal Component Factor Analysis (PCFA)

Before the formal analysis, the original data was screened for possible problems like missing data, non-normality, and collinearity. First, there were 11 missing values (0.58%), which were replaced with Mean Imputation. Second, because most responses lied between 4 and 7 on a Seven-Point Likert scale, the normality of the distribution of all areas was examined respectively by their Skew and Kurtosis. The normality assumption of the distribution of all areas was not rejected according to their Skewness Index (SI) and Kurtosis Index (KI). The biggest absolute value of SI was 2.178 while KI was 7.905, both of which were smaller than the recommended levels of 3 and 10. Finally, all bivariate correlations were reasonably less than 0.85, therefore no action was needed to eliminate or combine variables.

The data was then analyzed by Principal Component Factor Analysis (PCFA) with Varimax rotations by the statistical package of social science (SPSS). The Kaiser-Meyer-Olkin (KMO) measure of the sampling adequacy was 0.695 and the Bartlett Test of Sphericity was 833.223 ($P<0.000$), which indicated the suitability of the factor analysis of the data. According to the rule that eigenvalue should be greater than one (Zhang and Dong 2009), nine BIMM factors were identified to explain 72.609% of the total variance of the 27 areas. In order to obtain a more concise and interpretable structure of factors, areas with low loading (the factor loading < 0.65) or with substantial loading on more than one factor (the difference of one item's loading on different factors < 0.20) were removed (Hair et al. 2009). After four-iteration of PCFA, 14 consistent areas were retained and categorized into five factors, which accounted for 72.891% of the total variance. The factors structure was shown in Table 3.

There were four areas loaded highly on factor one. Process and technology innovation, Strategic planning, process and technology innovation, and applications focused on aligning the planning and innovation of BIM technology and process with the strategic objectives of the project. Quality control referred to the monitor and management of modeling service or phase-product throughout the process. Considering both above, factor one was defined as Planning and Management of Process and Technology.

Factor two included four areas of reward system, change management, role, and senior leadership. Most of these areas aligned on the regulation of the role, responsibility, and reward of the project team, therefore the second factor was understood as Team Structure.

The third factor consisted of hardware equipment and hardware upgrade. The acquisition and upgrade of hardware is an important indicator of a project's technology strength, because it offers physical artifacts needed for BIM implementation. Considering the nature of these two areas, Factor 3 was entitled as Hardware.

Factor four extracted two areas of documentation and modeling standards (DMS) and standardized operation process (SOP). DMS set the rules and format for preparing documents and information while SOP standardized the activities to create, collect, communicate, and share information. Considering the nature of these two areas, factor 4 was therefore named as Process Definition, the goal of which is to standardize the operation process and develop process assets like standards that facilitate the creation of meaningful data for the project (SEI 1994).

Real-time data and lifecycle process were extracted as significant in the fifth factor. Real-time data is important because the timely input and update of data will facilitate decision-making process. The lifecycle process referred to the implementation of BIM throughout the lifecycle of a building by coordinating related stakeholders. It is important because it maximizes the value of information, reduces the waste of duplicative data creation and gathering, as well as the conflict among different source of information (NIBS 2007). Both areas concerned with the timeliness and continuity of data collection, management, and distribution. Thus, factor 5 was interpreted as Information Management.

Table 3: Factor structure and variance explained

	Factors					Communalities
	1	2	3	4	5	
Process & Tech. Innovation	**0.809**	0.291	0.095	-0.009	-0.032	0.749
Quality control	**0.798**	0.042	0.073	0.231	0.108	0.708
Strategic planning	**0.764**	0.383	0.022	0.043	0.118	0.747
Applications	**0.721**	0.014	0.500	-0.095	-0.132	0.796
Reward system	0.101	**0.791**	0.210	-0.024	0.019	0.680
Change management	0.133	**0.788**	0.079	0.056	0.162	0.674
Role	0.200	**0.705**	0.197	0.301	-0.088	0.674
Senior leadership	0.234	**0.678**	0.054	0.297	0.002	0.606
Hardware equipment	0.233	0.139	**0.872**	0.117	0.151	0.871
Hardware upgrade	0.056	0.300	**0.857**	0.053	0.038	0.832
Doc. & Modeling Standards	0.185	0.088	0.103	**0.820**	-0.149	0.747
SOP	-0.068	0.249	0.014	**0.818**	0.203	0.777
Real-time data	-0.111	-0.102	0.228	-0.038	**0.804**	0.722
Lifecycle process	0.190	0.191	-0.077	0.062	**0.735**	0.622
Eigenvalue	4.654	1.717	1.472	1.225	1.136	
% of Variance (Rotation)	19.009	19.005	13.721	11.500	9.656	
Cronbach's Alpha						0.830
Kaiser-Meyer-Olkin Measure of Sampling Adequacy						0.726
Bartlett's Test of Sphericity: Approx. Chi-Square (Sig.)						384.641 (0.000)

Notes: Significant factor loadings are highlighted. The factors represent: 1. Planning and Management of process and technology; 2. Team Structure; 3. Hardware; 4. Process definition; 5. Information Management

3.2.3 Factors Ranking

In order to get a general priority of the identified factors, the BIMM factors were then ranked according to Eq. 1 (Wong and Cheung 2004):

$$F_i = \frac{\sum_{j=1}^{n} A_{ij}}{n} \tag{1}$$

where F_i is the score of the i^th^ factor, and A_{ij} is the mean score of the j^th^ area of the i^th^ factor. The score of each factor is the arithmetic mean scores of the mean scores of their corresponding areas. For example, Process Definition and Management (Factor 1) consists of six areas. Hence, the factor score was computed as Eq.2:

$$F_i = (6.505 + 5.675 + 5.653 + 5.917 + 5.855 + 6.032) / 6 = 5.864$$

(2)

The ranking for the factor scores is listed in Table 4. Among the five factors, Process Definition ranked first while Hardware ranked the last.

3.3 Discussion

It was noticed that during quite the same time of the implementation of this research project, there were other similar research efforts working on BIM maturity, like bimSCORE of the Center for

Table 4: Factor scores ranking

No. Factor Description	Factor Score	Ranking
4. Process Definition	6.100	1
1. Planning and Management of Process and Technology	5.850	2
2. Team Structure	5.728	3
5. Information Management	5.601	4
3. Hardware	5.195	5

Integrated Facility Engineering (CIFE) (Stanford University 2011) and Major BIM Research Study for the Construction Industry by Stevens Construction Institute and the University of Florida's Center for Advanced Construction Information Modeling (N.D.). Due to the limited exposure of information related to Major BIM Research Study, only the key dimensions of CIFE's bimSCORE were listed and compared with the five-factor framework prosed in this research. The four factors of CIFE's bimSCORE includes Planning, Adoption, and Technology, and Performance. As shown in Table 5, except the last factor of Performance, there were overlap of factors exposed in bimSCORE and the BIMM framework because of the similar items. With the goal to develop a framework to measure the extent to which BIM is explicitly "defined, managed, integrated, and optimized" (Succar 2010, p. 84), this research focused on the evaluation of BIM service and the factors directly contributing to the BIM implementation, including the dimensions of technology, process, information, and policy. The business values or benefits of BIM like higher return on BIM investment, better construction performance, and improved trust or satisfaction of the owner, were not considered in the framework.

Among the five factors, factors related to process, people, and information ranked comparatively higher than the factor of hardware, which was consistent with the finding of shifted BIM focus from "technical issues" to the issues of information, process (McGraw-Hill 2009), and people (Gilligan and Kunz 2007). The small difference of the scores further implied that factors related to process, people, and information are equally important in measuring BIMM.

Table 5: Comparison of the factors and areas proposed by bimSCORE and BIMM framework

CIFE/BIMM	Planning & Mgmt. of Process & Tech.	Team Structure	Hardware	Process Definition	Information Management (IM)
Planning	"Objective" / Strategic Planning	N/A	"Preparation"/ Equipment& Upgrade	"Standard" / DMS & SOP	N/A
Adoption	N/A	"Organizational structure"/ Role & Reward & Leadership	N/A	N/A	Phase covered & Communication / lifecycle process
Technology	N/A	N/A	N/A	N/A	"Maturity" & "Coverage" & "Integration" / lifecycle process & real-time data
Performance	N/A	N/A	N/A	N/A	N/A

4. CONCLUSION

It was noticed the initial pool of 27 areas and the criteria to filter BIM-related experts were set based on the opinion of the authors, which may be biased by their expertise, experience and knowledge. In addition, the importance of each area for measuring BIMM in the questionnaire was rated based on the respondents' perception, the reliability and validity of which were limited by the knowledge and cooperation of the subjects. What is more, given different technology capability, operation process, and business objectives, the relative importance of these factors may vary.

For the first limitation, besides comparatively exhausting related literature, the structure of the framework was further confirmed by comparing to independent research effort about BIM maturity. Besides, the reliability of the questionnaire instrument was confirmed based on empirical evidence to overcome the second issue. Finally, although the prioritization of the factors is "case-based", a general ranking based on BIM-related experts may offer managers or users to better understand, implement, or improve BIM more effectively, not to mention that the ranking of the factors consisted with the related research findings.

A comprehensive and precise framework for measuring BIMM was proposed based on literature review and empirical analysis of perception of academic and industry BIM-related experts outside the USA. Further research will be conducted to compare the similarity and difference of the perceived frameworks based on perception of BIM-related experts within and outside the USA.

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