Global Stakeholders' Perception of Key BIM Maturity Indicators

Yunfeng Chen[1], Hazar Dib[2], Robert F. Cox[3], Mark Shaurette[4], Mihaela Vorvoreanu[5], Celine Manoosingh[6], and Marcel Maghiar[7]

1) Assistant Professor, Department of Civil Engineering and Construction Management (CECM), Georgia Southern University, Statesboro, GA, USA. Email: ychen@georgiasouthern.edu
2) Associate Professor, Department of Construction Management Technology (CMT), Purdue University, West Lafayette, IN, USA. Email: hdib@purdue.edu
3) Associate Dean of Globalization and Engagement, Professor of CMT Department, Purdue University, West Lafayette, IN, USA. Email: rfcox@purdue.edu
4) Associate Professor, Department of CMT, Purdue University, West Lafayette, IN, USA. Email: mshauret@purdue.edu
5) Associate Professor, Department of Computer Graphics Technology, Purdue University, West Lafayette, IN, USA. Email: mihaela@purdue.edu
6) Assistant Professor, Department of CECM, Georgia Southern University, Statesboro, GA, USA. Email: cmanoosingh@georgiasouthern.edu
7) Assistant Professor, Department of CECM, Georgia Southern University, Statesboro, GA, USA. Email: mmaghiar@georgiasouthern.edu

Abstract:

This study investigates the prioritization of key BIM Maturity (BIMM) indicators by stakeholders with experience in BIM-assisted projects. A literature review was conducted to identify an initial pool of BIMM indicators, based on which a survey was generated and administered to global BIM-related practitioners. Descriptive statistics and ranking comparison are used to study the perceived importance of each BIMM indicator for practitioners with different business types and experiences. The results show that although there is a general agreement in the key BIMM indicators and the key dimensions among stakeholders with different profiles, there are significant differences in the perceived importance and ranking of some specific indicators and dimensions. This research has both theoretical and practical contributions. Theoretically, this study offers empirical evidence and possible justification about the underlying differences and agreement among global practitioners with different profiles. Practically, current BIM practitioners can improve their BIM implementation by focusing on the key areas of BIMM and by better understanding the perceived difference of different stakeholders. Meanwhile, potential adopters of BIM can understand what BIM implementation really entails and the perceived focus of BIMM by practitioners with different years of experience.

Keywords: Building Information Modeling, Maturity, Stakeholder, Global, Mean, Project

1. INTRODUCTION

BIM Maturity (BIMM) refers to the extent to which BIM is "explicitly defined, managed, integrated, and optimized" (Succar 2010). A BIMM model includes a compilation of key BIMM indicators, which can be used to initiate, evaluate, and compare BIM implementation. A mature implementation of BIM requires an optimal growth among different key dimensions of BIM. An incompatible development among various aspects can lead to different levels of BIMM (Gu and London 2010) or even project failure (Gu et al. 2014). Additionally, previous studies found that with the increase of BIMM, the performance, process control and predictability of any business can improve (McCormack and Lockamy 2004; Paulk et al. 1995). Therefore, it is important to identify the key BIMM indicators to facilitate the initiation and evaluation of BIM, as well as project success. It was also found that the perception of BIM varied among disciplines and countries (Gu and London 2010). Thus, it is important to list and compare the key BIMM indicators as perceived by professionals with different backgrounds.

Models with BIMM indicators exist in previous literature, however, most studies are very limited in their theoretical justifications and account for indicators only in certain dimension (National Institute of Building Science (NIBS) 2007). In addition, even there are some empirical research collecting insights from the industry practitioners, the studies are either limited in their sample size (Gu and London 2010) or in the comprehensiveness of their indicators (McGrawHill 2008; McGrawHill 2012). Moreover, it is found by some researchers that there are different adoption levels and understanding of BIM within a country and among countries (Chen 2013; Gu and London 2010). However, very limited comprehensive study is conducted to compare the perceived prioritization of key BIMM indicators by global practitioners with different businesses and experiences. BIM that may seem mature to a client may be completely immature for an architect or a contractor. Similarly, a project that is considered mature with BIM implementation by a practitioner with one year of BIM-related experience might not be considered so a practitioner with more than eight years of BIM-related experience.

The objective of this study is to fill the gaps of the existing studies and to present findings from a survey of global practitioners about their perception of BIMM indicators through descriptive statistics and ranking comparison. The objectives of this study include (1) the identification of key BIMM indicators and dimensions, (2) the test and identification of perceived difference in the mean and ranking of BIMM indicators among professionals with different profiles, and (3) the discussion of possible reasons to explain the above underlying consensus and disagreement among global professionals. The practitioners with a specific profile can get a better idea about themselves, as well as the focus and the challenges of the industry. The practitioners can also use the key BIMM indicators here to initiate, evaluate, and improve their BIM implementation according to their business profile and experience.

2. LITERATURE REVIEW

Due to the multidimensional nature of BIM, it is difficult to develop a matrix with a comprehensive list of BIMM indicators. Based on an extensive literature review, four dimensions emerged, including technology, information, process, and people. The literature that covers one dimension or a combination of any dimension is reviewed next.

Some studies focus in one dimension of BIM. For example, Capability Maturity Model (CMM) developed by National Institute of Building Science is limited to the evaluation of information management of BIM (National Institute of Building Science (NIBS) 2007). BIM competency framework developed by Giel and Issa covers the dimension of people (Giel and Issa 2013); however, there is limited discussion about other dimensions.

Some studies explore two dimensions of BIM. For example, BIM delivery matrix proposed by the Alliance for Construction Excellence discusses about the information and technology dimensions without the consideration of the people and process dimensions(Alliance for Construction Excellent (ACE) 2008).

Some studies explore three dimensions of BIM. For example, BIM competency set developed by Succar covers the dimensions of technology, process, and people (Succar 2008). However, there is limited discussion about information (Chen et al. 2012). Gu and London identified nine technical and non-technical issues related to process, technology, and people for BIM implementation, while information issues are not considered (Gu and London 2010).

Other studies cover all the four dimensions. For example, Computer Integrated Construction (CIC) developed two comprehensive guides to plan the execution of BIM. However, the guides were designed as guidelines instead of evaluation matrix for BIM. In addition, limited details were offered in justifying the assessment variables.

There is no shortage of theoretical frameworks with key BIM/ BIMM indicators. However, most studies lack comprehensiveness and are limited to certain dimensions. Moreover, few studies offer a solid theoretical justification to their indicators. More significantly, limited world-wise empirical evidence is offered to gain insight about the agreement and disagreement of the perception of BIM-related practitioners in the prioritization of BIMM indicators. An comprehensive pool of 27 BIMM indicators based on a synthesis of previous literature was proposed by Chen et al., as shown in Table 1 (Chen et al. 2012). Based on the nature of the BIMM indicators, the framework covers all the four dimensions. This study is conducted to further overcome the third limitation to gain insights of the global practitioners in their perception of the key BIMM indicators.

3. RESEARCH METHODOLOGY

The global practitioners' perception in the importance of each BIMM indicators was collected through an online questionnaire survey. The data analysis consists of two parts, (Part 1) the analysis of the demographic information and (Part 2) the analysis of the mean ranking of the BIMM indicators. The analysis of the demographic information summarizes the experience of the respondents, the demographic information of their companies, as well as the profiles of their BIM-assisted projects. Then, descriptive statistics such as mean and standard deviation are used to rank the preference of practitioners with different profiles on the proposed BIMM indicators. Due to the rich profile of the respondents, they were compiled into different groups according to the business type of their companies and the practitioners' BIM-related experience in term of the number of years in working with BIM. To further identify the agreement on each BIMM indicator, the ranking for the various indicators by practitioners with different profiles is compared to compute the ranking difference. It is considered significant when a rank difference is not less than half of the number of the indicators (Ugwu 2005). For this study, when a ranking difference is more than 13, it is considered there exists a significant ranking difference of the indicator among different practitioners. This approach was also used in previous studies in comparing ranking difference (Ugwu 2005).

3.1 Data Collection

The data about the perceived importance of each BIMM indicator was collected through an online questionnaire survey. The questionnaire includes four parts, including questions about (1) companies' demographic information and BIM-related experience, (2) practitioners' demographic information and BIM-related experience, (3) practitioners' perceived importance of each BIMM indicator, and (4) their comments. The population for this research is global practitioners with BIM-related experience. As shown in Table 2, the sample includes 498 global BIM-related practitioners, including 373 USA practitioners and 125 international practitioners. 141 responses were received. To safeguard the quality of the collected data, only the responses from the respondents with more than one year direct working experience with BIM and with more than two BIM-assisted projects were used for analysis. After the data screening, 109 responses were used for further data analysis.

Table 1. BIMM Dimensions and Indicators (Chen 2013)

BIMM Dimension	BIMM Indicator
Technology (Chen 2013; Jung and Joo 2011; Succar 2010)	Software Applications Interoperability Hardware Equipment Hardware Upgrade
Information (Chen et al. 2014; Computer Integrated Construction (CIC) 2011; National Institute of Building Science (NIBS) 2007)	Information Delivery Method (IDM) Information Assurance Data Richness Real-Time Data Information Accuracy Graphics Geospatial Capability Work Flow Documentation and Modeling Standards (DMS)
Process (Giel and Issa 2013; Gu and London 2010; Mom et al. 2011; Succar 2010)	Process & Tech Innovation (PTI) Strategic Planning Lifecycle Process Change Management Risk Management Standard Operating Process (SOP) Quality Control Specification
People (Chen 2013; Computer Integrated Construction (CIC) 2013; Gu and London 2010; Gu et al. 2014)	Senior Leadership Role Reward System Competency Profile Training Program Training Delivery Method (TDM)

Table 2. Survey Questionnaire Response Rate (Chen 2013)

Perspective	Sent	Received (%)	Valid (%)	Qualified (%)
USA Industry	373	92 (24.66%)	81 (21.72%)	75 (20.11%)
Non-USA Industry	125	49 (39.20%)	40 (32.00%)	34 (27.20%)
Total	498	141 (28.31%)	121 (24.30%)	109 (21.89%)

3.2 Data Analysis – Demographic Information

The first two parts of the questionnaire collect information about the companies and the practitioners. In the following text, the collected information about each part is analyzed respectively.

The first part asks questions about company information, including its business type, year rage to use BIM, and primary building type of BIM-assisted projects. As shown in Figure 1, the sample covers a broad range of business types, including 6% owner/developer (O/D), 27% architect/engineer (A/E), 22% general contractor /construction manager (GC/CM), and 5% subcontractor. In addition to the typical project stakeholders, there is also a large percentage of consultant (17%) and software vendor (17%). As shown in Table 3, most of the companies that the respondents worked for started to use BIM between 2000 and 2010. Specially, 45% companies began to employ BIM sometime between 2006 and 2010, and 30% started to use BIM sometime between 2000 and 2005. Around 20% companies began their exploration of BIM before 2000. In terms of building type, the most common building types are complex commercial (25%) and healthcare (20%) buildings as shown in Figure 2. It is interesting to see that residential projects are the third most popular building type assisted by BIM. There is an equal distribution for the rest of building types, such as educational, institutional, entertainments, and others.

The second part of the questionnaire asks about respondents' BIM-related experience. As shown in Figure 3, most respondents (35%) had been working with BIM between three and five years. A significant portion (30%) of respondents has worked with BIM for more than eight years.

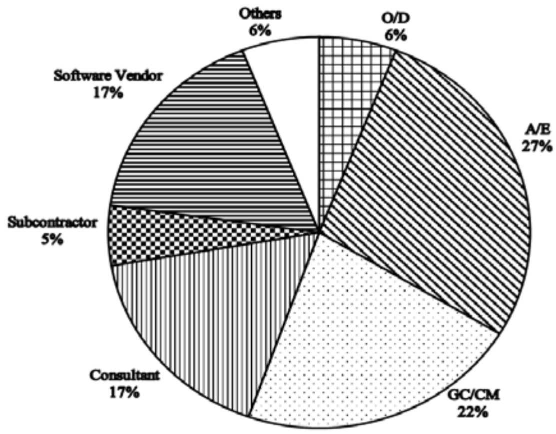

Figure 1. Breakdown of survey respondents' companies by business type

Table 3. Year range that the respondents' companies started to use BIM

	Global: Frequency (%)
Prior to 1990	8 (7%)
1990-1999	14 (13%)
2000-2005	33 (30%)
2006-2010	49 (45%)
Not Yet	1 (1%)
No Indicated	4 (4%)
Total	109 (100%)

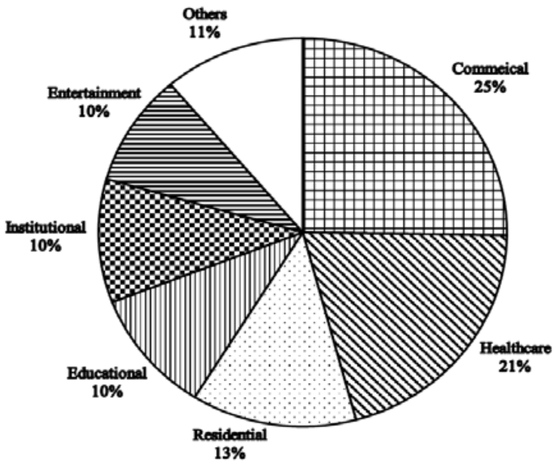

Figure 2. Breakdown of survey respondents' projects by building type

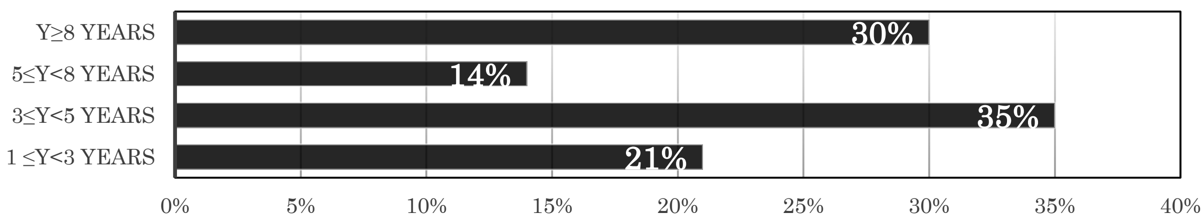

Figure 3. Percentage of survey respondents by their years of experience with BIM

3.3 Data Analysis – Comparison of Indicator Mean and Ranking

Descriptive statistics are used in this section to discuss the results of the questionnaire-based BIMM indicators. Due to the rich profiles of the respondents, the mean scores for the proposed 27 BIMM indicators are calculated and analyzed in the following subsections respectively in terms of business type and practitioners' BIM-related experience in terms of the number of years. It reflects the perceptions of the practitioners with different backgrounds and cumulative ranking. The difference of the rankings is further computed to identify the agreement on each indicator by practitioners with different profiles. Then the top 10 BIMM indicators by the various respondents were summarized separately and mapped into main four dimensions of technology, information, process, and people.

(1) Business Type

The respondents to the survey of this study cover a broad range of business types, including owner/developer (O/D), architect/engineer (A/E), general contractor/construction manager (GC/CM), subcontractor, consultant, and software vendor. Table 4 shows the mean scores, standard deviation (SD), and ranking of each BIMM indicator based on the perception of practitioners with different business types. The biggest rank difference among the groups (except the group of others) is listed in the last column of Table 4. The minimum mean values for the BIMM indicators for the various stakeholders respectively are geospatial capability with 5.43 (O/D), reward system with 4.50 (A/E), reward system with 4.67 (GC/CM), reward system with 3.80 (Subcontractor), reward system with 5.28 (Consultant), hardware upgrade with 4.89 (Software Vendor), and reward system with 4.67 (Others). Table 5 summarizes the respective top ten indicators ranked by the various stakeholders and maps these into the four dimensions. Some of the findings under different dimensions are discussed next.

Technology: The indicator of interoperability was consistently perceived as one of the top ten indicators by all stakeholders. It is interesting to see that the indicator of software applications was valued by A/E and consultant, while the other stakeholders did not value it as much. According to the cutoff point of 13, there is a significant difference in the ranking of the software applications indicator among stakeholders with different business types. Further investigation reveals the difference lies between O/D and A/E, which indicates that the A/E valued the software application in BIM implementation significantly more than O/D. This confirms that A/E claimed BIM more as a technology while O/D perceived BIM more as a process (Chen et al. 2014).

Table 4. The perception of key BIMM indicators by stakeholders with different business types

	Mean of Perceived Importance (SD, Rank)							
	Owner/Developer (N=7)	Architect/Engineer (N=31)	GC/CM (N=24)	Subcontractor (N=5)	Consultant (N=18)	Software Vendor (N=18)	Others (N=6)	Biggest Rank Difference (except others)
Software Applications	5.86 (0.69, 18)	**6.26 (1.03, 3)**	5.75 (1.29, 18)	5.80 (1.10, 20)	**6.33 (0.69, 5)**	6.06 (1.06, 13)	5.17 (1.72, 26)	**17**
Interoperability	**6.29 (0.49, 4)**	**6.03 (1.05, 7)**	**6.33 (0.64, 1)**	**6.60 (0.55, 2)**	**6.67 (0.49, 1)**	**6.39 (0.85, 5)**	**6.50 (0.55, 3)**	6
Hardware Equipment	5.71 (0.95, 20)	5.68 (1.11, 16)	5.83 (0.92, 14)	5.40 (1.14, 23)	5.78 (0.65, 21)	5.17 (1.51, 26)	5.83 (0.41, 11)	12
Hardware Upgrade	5.57 (0.79, 23)	5.35 (1.25, 23)	5.63 (1.14, 21)	5.00 (1.41, 26)	5.44 (0.78, 25)	4.89 (1.75, 27)	5.83 (0.75, 13)	4
IDM	6.00 (0.58, 12)	**6.29 (1.01, 2)**	**5.96 (0.81, 7)**	**6.60 (0.55, 2)**	**6.56 (0.62, 2)**	**6.61 (0.85, 2)**	**6.67 (0.82, 2)**	10
Information Assurance	**6.43 (0.79, 3)**	**5.97 (1.08, 8)**	**6.00 (0.72, 4)**	**6.40 (0.55, 4)**	**6.39 (0.61, 4)**	**6.56 (0.71, 3)**	**6.50 (0.84, 5)**	5
Data Richness	6.00 (1.00, 15)	5.90 (0.91, 11)	**5.92 (0.78, 10)**	6.00 (1.00, 13)	5.89 (1.13, 18)	**6.17 (0.86, 9)**	5.83 (0.75, 13)	9
Real-Time Data	6.00 (0.82, 13)	5.71 (1.04, 15)	5.79 (1.02, 15)	5.80 (0.45, 16)	5.72 (1.07, 22)	5.56 (1.15, 21)	5.17 (0.41, 25)	9
Information Accuracy	**6.71 (0.49, 1)**	**6.42 (1.03, 1)**	**6.33 (0.70, 2)**	**6.80 (0.45, 1)**	**6.33 (0.84, 6)**	**6.83 (0.38, 1)**	**6.67 (0.52, 1)**	5
Graphics	5.71 (0.95, 20)	5.19 (1.40, 26)	5.33 (1.10, 25)	5.60 (0.55, 21)	5.61 (0.78, 23)	5.33 (0.91, 24)	5.33 (0.82, 24)	6
Geospatial Capability	5.43 (1.27, 27)	5.29 (1.22, 25)	5.67 (1.20, 20)	5.40 (1.14, 23)	5.89 (1.02, 17)	5.39 (1.04, 23)	5.67 (0.82, 18)	10
Work Flow	**6.14 (0.69, 8)**	5.77 (0.96, 14)	5.54 (1.18, 23)	**6.20 (0.45, 7)**	**6.11 (0.76, 7)**	**6.22 (0.88, 6)**	5.83 (0.41, 11)	**17**
DMS	**6.29 (0.76, 5)**	**6.10 (0.85, 5)**	**6.08 (0.88, 4)**	5.80 (0.84, 17)	6.00 (0.91, 11)	**6.18 (0.81, 7)**	5.83 (1.33, 17)	13
PTI	5.71 (0.76, 19)	5.61 (1.20, 17)	5.71 (1.12, 19)	5.80 (0.84, 17)	5.94 (0.87, 14)	6.11 (0.76, 12)	5.67 (0.82, 18)	7
Strategic Planning	**6.29 (0.76, 5)**	**5.90 (0.87, 10)**	5.92 (1.10, 11)	**6.20 (0.84, 8)**	5.94 (0.87, 14)	**6.17 (0.86, 9)**	5.83 (1.17, 16)	9
Lifecycle Process	**6.29 (0.76, 5)**	5.32 (1.22, 24)	5.46 (1.32, 24)	**6.00 (0.71, 10)**	5.83 (0.79, 20)	5.94 (1.43, 16)	5.83 (0.98, 15)	**19**
Change Management	**6.14 (0.69, 8)**	5.90 (1.04, 12)	**5.96 (1.08, 8)**	**6.40 (0.89, 5)**	5.94 (0.80, 12)	6.17 (0.99, 11)	**6.17 (0.41, 6)**	7
Risk Management	5.57 (0.79, 23)	5.47 (0.94, 20)	5.79 (1.22, 17)	6.00 (1.00, 13)	**6.06 (0.73, 10)**	5.94 (0.75, 15)	5.50 (1.05, 21)	13
SOP	5.71 (1.11, 22)	5.60 (0.93, 18)	5.88 (0.90, 13)	5.20 (0.84, 25)	**6.11 (0.90, 9)**	5.76 (0.90, 19)	5.50 (1.38, 23)	**16**
Quality Control	6.00 (1.00, 15)	**6.17 (0.70, 4)**	**5.96 (1.08, 8)**	**6.00 (0.71, 10)**	**6.11 (0.76, 7)**	**6.18 (0.81, 7)**	**6.50 (0.55, 3)**	11
Specification	**6.14 (0.69, 8)**	5.57 (0.94, 19)	5.33 (1.47, 26)	**6.20 (1.10, 9)**	5.83 (0.71, 19)	5.82 (0.88, 17)	**6.00 (0.63, 8)**	**18**
Senior Leadership	**6.71 (0.49, 1)**	**5.97 (1.22, 9)**	**6.25 (0.79, 3)**	**6.40 (0.89, 5)**	**6.44 (0.71, 3)**	**6.44 (0.71, 4)**	**6.00 (1.67, 10)**	8
Role	6.00 (1.15, 17)	5.40 (0.77, 22)	**6.00 (1.02, 6)**	5.40 (0.89, 22)	5.94 (0.80, 12)	5.65 (0.79, 20)	5.50 (1.05, 21)	**16**
Reward System	5.57 (0.79, 23)	4.50 (1.31, 27)	4.67 (1.37, 27)	3.80 (1.79, 27)	5.28 (0.90, 27)	5.53 (1.13, 22)	4.67 (0.52, 27)	5
Competency Profile	6.00 (0.82, 13)	5.87 (0.90, 13)	5.79 (1.10, 16)	**6.00 (0.71, 10)**	5.41 (0.87, 26)	5.82 (0.95, 18)	**6.17 (0.98, 7)**	**16**
Training Program	6.14 (0.90, 11)	**6.07 (0.79, 6)**	5.92 (1.28, 12)	6.00 (1.00, 13)	5.94 (0.94, 16)	6.00 (0.87, 14)	**6.00 (0.63, 8)**	10
TDM	5.57 (1.13, 26)	5.47 (1.01, 21)	5.54 (1.14, 22)	5.80 (0.84, 17)	5.61 (0.98, 24)	5.29 (1.16, 25)	5.67 (1.51, 20)	9

Notes: Bolden Mean, SD, and ranking indicate that the BIMM indicator is among the top ten BIMM indicators as rated by the corresponding practitioners. Bolden rank difference indicates that the rank difference is significant.

Table 5. Top ten BIMM indicators perceived by stakeholders with different business types

	Owner/Developer	Architect/Engineer	GC/CM	Subcontractor	Consultant	Software Vendor
Technology	**Interoperability (4)**	Software Applications (3), **Interoperability (7)**	**Interoperability (1)**	**Interoperability (2)**	Software Applications (5), **Interoperability (1)**	**Interoperability (5)**
Information	**Information Assurance (3)**, **Information Accuracy (1)**, Work Flow (8), DMS (5)	IDM (2), **Information Assurance (8)**, **Information Accuracy (1)**, DMS (5)	IDM (7), **Information Assurance (4)**, Data Richness (10), **Information Accuracy (2)**, DMS (4)	IDM (2), **Information Assurance (4)**, **Information Accuracy (1)**, Work Flow (7)	IDM (2), **Information Assurance (4)**, **Information Accuracy (6)**, Work Flow (7)	IDM (2), **Information Assurance (3)**, Data Richness (9), **Information Accuracy (1)**, Work Flow (6), DMS (7)
Process	Strategic Planning (5), Lifecycle Process (5), Change Management (8), Specification (8)	Strategic Planning (10), **Quality Control (4)**	Change Management (8), **Quality Control (8)**	Strategic Planning (8), Lifecycle Process (10), Change Management (5), **Quality Control (10)**, Specification (9)	Risk Management (10), SOP (9), **Quality Control (7)**	Strategic Planning (9), **Quality Control (7)**
People	**Senior Leadership (1)**	**Senior Leadership (9)**, Training Program (6)	**Senior Leadership (3)**, Role (6)	**Senior Leadership (5)**, Competency Profile (10)	**Senior Leadership (3)**	**Senior Leadership (4)**

Note: Bolden BIMM indicators are the indicators that were consistently valued by all the stakeholders.

Information: The indicators of information assurance and information accuracy were consistently rated within the top ten indicators by all stakeholders. It is also interesting to see that compared with other stakeholders, O/D did not value information delivery method (IDM) as much. One possible explanation is that the other stakeholders valued the approach to deliver information because they are creators and users of the BIM model, while owner focuses more on the whole process and the final result. Most of the top ten indicators of A/E, GC/CM, consultant, and software vendor gather under the dimension of information. There is a significant difference in the ranking of the work flow indicator between the group of GC/CM and the other groups.

Process: Except O/D, the indicator of quality control was ranked within the top ten indicators by all the other stakeholders. Most of the O/D's top ten indicators fell under the dimensions of information and process. In addition, subcontractor showed particular preference for indicators that measure the process of BIM implementation. There is a significant difference in the ranking of the indicators of lifecycle process, SOP, and specifications mainly between the groups of O/D and GC/CM. Compared with GC/CM, O/D perceived BIM more as a process.

People: All the stakeholders ranked the indicator of senior leadership within top ten. This finding is consistent with many research related to the introduction of new technology, innovative process, quality control (Computer Integrated Construction (CIC) 2011; Jones 2000; Paulk et al. 1995). Significant difference in the ranking of the role indicator is found between the group of GC/CM and the groups of A/E and subcontractor. A/E is usually the lead of the BIM modeling, while subcontractor is working under GC/CM. Compared with A/E and subcontractor, GC/CM may have a higher need in a clear role definition for themselves and the other stakeholders.

Based on the number of the top ten BIMM indicators under each dimension, it turns out the dimension of information was valued the most by most stakeholders, followed by the dimension of process. This result is consistent with the research findings of other independent academic and industrial studies. Specifically, the finding agrees with the identified top obstacles of information and process for BIM improvement as reported by McGraw-Hill (McGraw-Hill 2009). In addition, it was identified by many researchers and practitioners that the focus of BIM implementations had shifted from the technology issue to other factors, such as information and process (Husin and Rafi 2013; Kiviniemi et al. 2008; Rekola et al. 2010).

(2) BIM-related Experience in Terms of Number of Years

In this section, all the respondents were compiled into groups based on theirs number of years directly working with BIM. There are four groups, including practitioners with BIM-related experience ranging from one to three years, three to five years, five to eight years, and more than eight years. Table 6 shows the mean scores, SD, and ranking of all BIMM indicators for the four groups. The BIMM indicator with the minimum mean value for all practitioners with different number of years in working with BIM is reward system, whose mean is 4.65 for practitioners with one to three years of experience, 5.08 for those with three to five years of experience, 4.67 for those with five to eight years of experience, and 4.9 for those with more than eight years of experience. Table 7 summarizes the top ten indicators for the four groups under the four dimensions.

Technology: The indicator of interoperability was still perceived as one of the top ten indicators by all practitioners with different years of experience in working with BIM. It is interesting to see that compared with practitioners with less experience, the group with more than eight-year experience with BIM did not value software application as much as other groups. This makes sense probably because the practitioners with more experience see the value of information management and people management to maximize the benefit of BIM. This result is consistent with other independent research findings (McGrawHill 2012).

Information: All the indicators of IDM, information assurance, and information accuracy were valued by all practitioners. It is interesting to see that except the most experienced users, all practitioners perceived DMS as important. One possible explanation is that the users with more experience know better about how to solve the problems and risks in documentation and modeling process. Comparatively, the users with less experience might have more problems in solving problems and risks due to their limited experience and knowledge. Therefore, the practitioners with less experience valued the standardization of documentation and modeling process. It is also interesting to see that the practitioners with the most experience rated geospatial capability significantly higher than the other practitioners.

Process: Both the indicators of change management and quality control are valued by most practitioners. It is interesting to see that the more experience practitioners have, the less they value the regulation and control of a process. All the practitioners may encounter a variety of challenges and changes in the modeling process. For the practitioners with more experience, they emphasized the management of technology and process changes. For the practitioners with less experience, because they have limited experience in dealing with a variety of changes and challenges in the modeling process, they might value the regulation and the control of the process more. Especially, as shown in Table 6, the practitioners with the least experience rated specification significantly higher than the other practitioners.

People: It is interesting to see that except the first group with the least BIM-related experience (one to three years), all the other practitioners valued the indicator of senior leadership and some other indicator in the people dimension. It is probably because with more experience, the practitioners realized the importance of the support from their senior leadership to the successful implementation of BIM.

Table 6. The perception of key BIMM indicators by stakeholders with different years of experience in BIM

	Mean of Perceived Importance (SD, Rank)				
	1 ≤Y<3 Years (N=23)	3≤Y<5 Years (N=38)	5≤Y<8 Years (N=15)	Y≥8 Years (N=33)	Biggest Rank Difference
Software Applications	**6.17 (0.72, 6)**	**6.11 (0.95, 10)**	**6.13 (0.64, 6)**	5.76 (1.54, 16)	10
Interoperability	**6.52 (0.67, 2)**	**6.32 (0.62, 2)**	**6.20 (0.56, 4)**	**6.27 (1.10, 4)**	2
Hardware Equipment	5.83 (0.83, 19)	5.71 (0.90, 18)	5.80 (0.94, 15)	5.36 (1.34, 24)	9
Hardware Upgrade	5.35 (1.19, 25)	5.42 (1.18, 24)	5.53 (0.99, 22)	5.27 (1.42, 26)	4
IDM	**6.52 (0.59, 1)**	**6.26 (0.86, 3)**	**6.33 (0.49, 2)**	**6.27 (1.10, 4)**	2
Information Assurance	**6.22 (0.67, 5)**	**6.18 (0.80, 7)**	**6.20 (0.86, 5)**	**6.27 (1.01, 3)**	4
Data Richness	5.96 (0.88, 13)	5.90 (0.83, 14)	5.67 (0.90, 16)	**6.15 (0.97, 6)**	10
Real-Time Data	5.87 (0.76, 16)	5.55 (1.01, 23)	5.40 (1.18, 24)	5.88 (1.02, 13)	11
Information Accuracy	**6.48 (0.67, 3)**	**6.63 (0.63, 1)**	**6.40 (0.74, 1)**	**6.42 (1.00, 2)**	2
Graphics	5.30 (1.52, 26)	5.40 (0.68, 25)	5.67 (1.11, 18)	5.27 (1.07, 25)	8
Geospatial Capability	5.65 (0.89, 22)	5.29 (1.06, 26)	5.00 (1.25, 26)	**5.94 (1.17, 9)**	**17**
Work Flow	**6.04 (0.83, 10)**	5.87 (0.88, 15)	5.60 (0.91, 19)	**5.97 (1.07, 7)**	12
DMS	**6.26 (0.69, 4)**	**6.13 (0.99, 8)**	**6.07 (0.88, 9)**	5.87 (0.81, 14)	10
PTI	5.78 (0.67, 20)	6.00 (0.70, 12)	5.87 (0.74, 11)	5.52 (1.46, 22)	11
Strategic Planning	5.96 (0.93, 14)	6.05 (0.77, 11)	**6.07 (0.80, 8)**	5.91 (1.13, 12)	6
Lifecycle Process	5.83 (0.78, 18)	5.63 (1.10, 21)	5.60 (1.06, 21)	5.61 (1.54, 19)	2
Change Management	**6.04 (0.77, 9)**	**6.11 (0.76, 9)**	5.87 (0.83, 12)	**5.97 (1.26, 8)**	4
Risk Management	5.87 (0.76, 16)	5.74 (0.92, 17)	5.80 (0.86, 14)	5.65 (1.17, 18)	4
SOP	5.96 (0.83, 12)	5.82 (1.04, 16)	5.67 (0.90, 16)	5.58 (0.96, 20)	8
Quality Control	**6.09 (0.79, 7)**	**6.18 (0.77, 6)**	**6.33 (0.62, 3)**	5.94 (1.00, 11)	8
Specification	**6.09 (0.85, 8)**	5.68 (0.96, 19)	5.40 (1.24, 25)	5.55 (1.09, 21)	**17**
Senior Leadership	6.04 (0.88, 11)	**6.24 (0.91, 5)**	**6.13 (1.06, 7)**	**6.49 (1.03, 1)**	10
Role	5.70 (1.06, 21)	5.58 (0.72, 22)	5.60 (0.99, 20)	**5.94 (0.93, 10)**	12
Reward System	4.65 (1.34, 27)	5.08 (0.97, 27)	4.67 (1.50, 27)	4.90 (1.42, 27)	0
Competency Profile	5.55 (0.96, 23)	5.97 (0.75, 13)	**5.93 (0.80, 10)**	5.71 (1.16, 17)	13
Training Program	5.91 (0.79, 15)	**6.24 (0.88, 4)**	5.87 (0.99, 13)	5.84 (1.06, 15)	11
TDM	5.39 (0.84, 24)	5.66 (1.02, 20)	5.47 (1.36, 23)	5.45 (1.15, 23)	4

Notes: Bolden Mean, SD, and ranking indicate that the BIMM indicator is among the top ten BIMM indicators as rated by the corresponding practitioners. Bolden rank difference indicates that the rank difference is significant.

Table 7. Top ten BIMM indicators perceived by stakeholders with different years of experience in BIM

	1 ≤Y<3 Years	3≤Y<5 Years	5≤Y<8 Years	Y≥8 Years
Technology	Software Applications (6), **Interoperability (2)**	Software Applications (10), **Interoperability (2)**	Software Applications (6), **Interoperability (4)**	**Interoperability (4)**
Information	**IDM (1)**, **Information Assurance (5)**, **Information Accuracy (3)**, Work Flow (10), DMS (4)	**IDM (3)**, **Information Assurance (7)**, **Information Accuracy (1)**, DMS (8)	**IDM (2)**, **Information Assurance (5)**, **Information Accuracy (1)**, DMS (9)	**IDM (4)**, **Information Assurance (3)**, Data Richness (6), **Information Accuracy (2)**, Geospatial Capability (9), Work Flow (7)
Process	Change Management (9), Quality Control (7), Specification (8)	Change Management (9), Quality Control (6)	Strategic Planning (8), Quality Control (3)	Change Management (8)
People		Senior Leadership (5), Training Program (4)	Senior Leadership (7), Competency Profit (10)	Senior Leadership (1), Role (10)

Note: Bolden BIMM indicators are the indicators that were consistently valued by all the stakeholders.

It turns out that the information dimension was still valued by all practitioners with different number of years in working with BIM. This result confirms that all practitioners perceived that the center of BIM implementation is information (Chen et al. 2010; Kiviniemi et al. 2008; Smith and Tardif 2009). Especially, the practitioners with more than eight-year experience working with BIM had six out of the top ten BIMM indicators falling in the information dimension.

3. CONCLUSIONS

This paper analyzes the perceived importance of each BIMM indicator based on the response from BIM-related practitioners with different profiles in terms of business type and experience. For a detailed comparison of BIMM indicators and BIMM dimensions among practitioners with different categorization criteria, please refer to the previous sessions. The key findings and the common themes are summarized here, in terms of BIMM indicator, BIMM dimension, and ranking difference.

First, it turns out that the four indicators of interoperability, information accuracy, quality control, and senor leadership were consistently valued by most global BIM-related practitioners. In contrast, reward system was the least valued indicator by most respondents, followed by graphics and hardware upgrade. One possible explanation is that most projects (69%) were implemented with traditional delivery method (DBB, CM and DB), the reward system was comparatively mature. In addition, most practitioners did not valued graphics may because they realized that BIM is more a process and information modeling than a graphic technology (Chen 2013). Last, with the population and maturation of BIM, most projects may be already equipped with hardware. Therefore, hardware upgrade might not be valued as much.

Second, the dimension of information is the most valued dimension by global practitioners with different profiles, followed by the dimension of process. In comparison, the dimension of people got the least attention, followed by the dimension of technology. This research finding is consistent with other independent studies. Specifically, some practitioners and researchers found that the focus of BIM implementation has shifted from the technology factor to other factors such as information and process (Husin and Rafi 2013; Kiviniemi 2011; McGraw-Hill 2009; Rekola et al. 2010).

Last, there is a general agreement on the key indicators and the key dimensions among the practitioners with different business types and with different experiences. However, there are some significant differences in the perceived importance and ranking of some specific indicators and the second most important dimensions among practitioners with different profiles. The identified disagreement among the practitioners with different profiles is consistent with the findings of different understanding within and between countries by other researchers (Gu and London 2010).

This research has both theoretical and practical contributions. Theoretically, this study offers empirical evidence and possible justification about the underlying differences and agreement among global practitioners with different profiles. Practically, current BIM practitioners can improve their BIM implementation by focusing on the key areas of BIMM and by better understanding the perceived difference of different stakeholders. Meanwhile, potential adopters of BIM can understand what BIM implementation really entails and the perceived focus of BIMM by practitioners with different years of experience.

REFERENCES

Alliance for Construction Excellent (ACE) (2008). "Building Information Modeling: An Introduction and Best Methods Approach." Alliance for Construction Excellence, 8-16.

Chen, Y. (2013). "Measurement Models of Building Information Modeling Maturity." Ph.D., Purdue University, Ann Arbor.

Chen, Y., Dib, H., and Cory, C. (2010). "Using Object Oriented Database Approach to Enable Students Learn Industry Practices." *27th International Conference on Application of IT in the AEC Industry & Accelerating BIM Research Workshop*Cairo, Egypt.

Chen, Y., Dib, H., and Cox, R. F. (2012). "A Framework for Measuring Building Information Modeling Maturity in Construction Projects." *14th International Conference on Computing in Civil and Building Engineering (ICCCBE)*Moscow, Russia.

Chen, Y., Dib, H., and Cox, R. F. (2014). "A measurement model of building information modelling maturity." *Construction Innovation: Information, Process, Management*, 14(2), 186-209.

Computer Integrated Construction (CIC) (2011). "BIM Project Execution Planning Guide." Pennsylvania State University (PSU), 125.

Computer Integrated Construction (CIC) (2013). "BIM Planning Guide for Facility Owners." The Pennsylvania

State University, University Park, PA, USA.
Giel, B., and Issa, R. R. A. (2013). "Framework for Evaluating the BIM Competencies of Building Owners." *2014 International Conference on Computing in Civil and Building Engineering*, American Society of Civil Engineers, Orlando, Florida, 552-559.
Gu, N., and London, K. (2010). "Understanding and facilitating BIM adoption in the AEC industry." *Automation in Construction*, 19, 988-999.
Gu, N., Singh, V., and London, K. (2014). "BIM Ecosystem: The Coevolution of Products, Processes, and People." *Building Information Modeling: BIM in Current and Future Practice*, John Wiley & Sons, Inc., New Jersey, 432.
Husin, R., and Rafi, A. (2013). "The impact of internet-enabled computer-aided design in the construction industry." *Automation in Construction*, 12(5), 509-513.
Jones, C. (2000). *Software Assessments, Benchmarks, and Best Practices*, Addison-Wesley Professional.
Jung, Y., and Joo, M. (2011). "Building information modelling (BIM) framework for practical implementation." *Automation in Construction*, 20, 126-133.
Kiviniemi, A. (2011). "The effects of integrated BIM in process and business models." *Distributed Intelligence in Design*, 125-135.
Kiviniemi, A., Tarandi, V., Karlshoj, J., Bell, H., and Karud, O. J. (2008). "Review of the Development and Implementation of IFC compatible BIM."Erabuild.
McCormack, K., and Lockamy, A. (2004). "The Development of a Supply Chain Management Process Maturity Model Using the Concepts of Business Process Orientation." *Supply Chain Management Journal*, 9(4), 272-278.
McGraw-Hill (2009). "SmartMarket Report-The Business Value of BIM: Getting Building Information Modeling to the Bottom Line." McGraw Hill Construction, 4-9.
McGrawHill (2008). "SmartMarket Repot - Building Information Modeling." N. W. J. Young, S. A. B. Jones, and M. Harvey, eds., McGraw-Hill Construction, New York, NY.
McGrawHill (2012). "SmartMarket Report: The Business Value of BIM in North America." McGrawHill Construction, 69.
Mom, M., Tsai, M.-H., and Hsieh, S.-H. (2011). "On Decision-Making and Technology-Implementing Factors for BIM Adoption." *International Conference on Construction Applications of Virtual Reality*.
National Institute of Building Science (NIBS) (2007). "United States National Building Information Modeling Standard." *Section 4 - Information Exchange Content*, 75-82.
Paulk, M. C., Weber, C. V., and Curtis, B. (1995). *The Capability Maturity Model: Guidelines for Improving the Software Process*, Addison-Wesley Professional, Reading, MA.
Rekola, M., Kojima, J., and Makelainen, T. (2010). "Towards Integrated Design and Delivery Solutions: Pinpointed Challenges of Process Change." *Architectural Engineering and Design Management*, 6, 264-278.
Smith, D. K., and Tardif, M. (2009). *Building Information Modeling: A Strategic Implementation Guide*, Wiley, Hoboken, New Jersey.
Succar, B. (2008). "Building information modelling framework: A research and delivery foundation for industry stakeholders." *Automation in Construction*, 18, 357-375.
Succar, B. (2010). "Building Information Modeling Maturity Matrix." *Handbook of Research on Building Information Modeling and Construction Informatics: Concepts and Technologies*, Information Science Publishing, 65-102.
Ugwu, O. O. (2005). "Key Performance Indicators for Infrastructure Sustainability - A Comparative Study Between Hong Kong and SOuth Africa." *Journal of Engineering, Design and Technology*, 3(1), 30-43.