Framework for Evaluating the BIM Competencies of Facility Owners

Brittany Giel[1] and Raja R. A. Issa, F.ASCE[2]

Abstract: The adoption of building information modeling (BIM) in the design and construction phases of building projects has increased considerably in recent years; however, its use in postconstruction is still lagging. Much of this is because of the lack of experience by owner organizations in using BIM during operations and maintenance (O&M). The architecture, engineering, construction, and operations (AECO) industry is undergoing a major paradigm shift that will require building owners to develop lifecycle-oriented BIM strategies. Consequently, owners will play a vital role in improving the maturity of future BIM-assisted projects through their requirements documentation, assessment of the quality and accuracy of BIM deliverables, and continued application of BIM during facilities management (FM). The primary objective of this research study was to develop a framework for building owner organizations to use in the assessment of their BIM competency. Using the Delphi technique, 66 critical factors that are influential in the evaluation of owners' BIM competency were identified and prioritized on the basis of the perceptions of 21 prequalified BIM experts. The data derived from the Delphi phase were then used to propose an assessment tool that allows owners to evaluate their operations across three diverse competency areas and 12 specifically tailored competency categories. These evaluations can then be used by owners to assess and expand their technical knowledge, improve their current BIM requirements, and increase the efficiency of their postconstruction operations. **DOI:** 10.1061/(ASCE)ME.1943-5479.0000378.

Author keywords: Building information modeling; Owners; Competency; Maturity; Facilities management; Operations and maintenance.

Introduction

Owners' involvement in building information modeling (BIM) proves to be gradually increasing, with more than 40% of U.S. owners predicting BIM use on more than three-quarters of their work within the next 2 years and 98% of United Kingdom owners indicating moderate BIM involvement now. But despite this rise in adoption, only 25% of U.S. public owners and 11% of the private sector indicate having set formal requirements for BIM. Of those users, 25% still indicate having set no standards or guidelines for their BIM execution efforts thus far (McGraw Hill Construction 2014). Furthermore, few documented cases of BIM implementation postconstruction still exist. Although they may see great value in using the model or its data during operations and maintenance (O&M), many owners are unsure of what BIM deliverables to require and lack the technical knowledge and resources required to operationalize the models they receive from designers and contractors. In fact, the greatest obstacle to BIM use as perceived by owners is a lack of qualified users on their staff and the cost of the initial training investment (McGraw Hill Construction 2014). This suggests a strong research need to assess the technical maturity and BIM readiness of the building owner population.

[1]Virtual Design and Construction (VDC) Engineer, Whiting-Turner Contracting Company, 300 East Joppa Rd., Baltimore, MD 21286. E-mail: brittany.giel@whiting-turner.com

[2]University of Florida Research Foundation and Holland Professor, M. E. Rinker, Sr., School of Construction Management, Univ. of Florida, Gainesville, FL 32611-5703 (corresponding author). E-mail: raymond-issa@ufl.edu

Note. This manuscript was submitted on October 2, 2014; approved on March 4, 2015; published online on April 28, 2015. Discussion period open until September 28, 2015; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, © ASCE, ISSN 0742-597X/04015024(15)/$25.00.

It is critical that the BIM competency of building owners be addressed if the architecture, construction, engineering, and operations (AECO) industry intends to achieve lifecycle use of building information models. Although there have been several attempts to evaluate the maturity of BIM execution, few studies have addressed the specific needs and information requirements of facility owners as a separate entity. Moreover, once BIM is fully embraced by the owner population, a quantitative method for benchmarking their progress and setting realistic goals for continuous improvement will be necessary.

The primary aims of this study were to identify what critical factors must be measured in the evaluation of building owners' BIM competencies; determine the perceived importance of those factors by leading experts in the research domain; and develop a framework for assisting owner organizations in evaluating their BIM competencies. The objectives of this study were to assemble a diverse panel of qualified BIM experts to participate in the Delphi technique survey; query the panel regarding what factors are most influential in evaluating building owners' BIM competencies; facilitate the panel in achieving consensus regarding the perceived importance of those factors; and create an assessment tool on the basis of the panel's decisions to assist owners in assessing the BIM capabilities of their existing personnel and operations.

Background

Since the late 1970s, the term maturity has been widely used to describe the organizational process and quality improvement strategies, particularly within the software industry. The first and most influential models to evaluate maturity were the quality management maturity grid by Crosby (1979) and the capability maturity model (CMM) of the Carnegie Mellon Software Engineering Institute (SEI) (Paulk et al. 1993). Paulk et al. (1993) also distinguished the difference between process capability, process performance, and process maturity in software development. They described process maturity as the extent to which a specific process is explicitly defined, managed, measured, controlled, and considered effective. Khoshgoftar and Osman (2009) defined a maturity model as a structured group of elements and practices that characterize effective processes and/or products consisting of a limited number of maturity levels that are sequential and characterized by specific requirements. There have been countless attempts to relate these concepts to other domains [Kaplan and Norton 1992; Watson and Seng 2001; Nightingale and Mize 2002; National Institute of Standards and Technology (NIST) 2012]. However, the most noteworthy models that have been adapted to the construction industry include standardized process improvement for construction enterprise (SPICE), project management process maturity (PM2), benchmarking and readiness assessment for concurrent engineering in construction (BEACON), verify end-user e-readiness using a diagnostic tool (VERDICT), the knowledge retention maturity model, and the construction supply chain maturity model (CSCMM) (Sarshar et al. 2000; Kwak and Ibbs 2002; Khalfan et al. 2001; Ruikar et al. 2006; Arif et al. 2009; Lockamy and McCormick 2004).

Evaluation of BIM Maturity

As early as 2007, several researchers began applying these same principles of process improvement to the BIM domain. The different BIM maturity assessment tools that have been proposed thus far tend to fall into two general categories: those that assess individual building projects assisted by BIM and those that assess the maturity of organizations or individuals implementing BIM processes.

National BIM Standard's CMM

The first effort towards BIM maturity evaluation began with the National BIM Standard's (NBIMS's) CMM, which was designed to help organizations evaluate their business practices and measure the degree to which BIM-assisted projects implemented a mature BIM standard. Evaluations in the CMM tool are on the basis of 11 areas of interest weighted against 10 increasing levels of maturity. The different levels of certification for building projects in the CMM are minimum, certified, silver, gold, and platinum BIM, for a maximum score of 100 points [National Institute of Building Sciences (NIBS) 2007; McCuen et al. 2012].

BIM Excellence

Soon after, Succar (2009) published a comprehensive BIM framework that outlined the conceptual underpinnings behind BIM research and delivery methods. At its core are multiple indices and metrics that can be used to assess BIM maturity on a number of different scales. He first proposed the BIM maturity matrix to evaluate teams and organizations implementing BIM on the basis of 10 key maturity areas (KMAs) evaluated across five maturity levels, one capability stage, and one organizational scale (Succar 2010). Later in 2013, he expanded on the framework and proposed an individual competency index (ICI) to evaluate individuals within professional and academic settings executing BIM (Succar et al. 2013). Succar's research framework has since evolved and been commercialized as BIM excellence (BIME), a BIM performance assessment and improvement program that may be customized to assess individual and team BIM competency, organizational capability, and maturity and overall project performance.

VDC Scorecard/bimSCORE

Similarly, Stanford's Center for Integrated Facility Engineering (CIFE) created the *VDC Scorecard* program in 2009 to evaluate and benchmark the maturity of virtual design and construction practices. The scorecard utilizes the results of four input survey forms related to planning, adoption, technology, and performance, subdivided into 10 dimensions and multiple individual innovation measures (C. Kam et al., "The formulation and validation of the VDC scorecard," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California; C. Kam et al., "The VDC scorecard evaluation of AEC projects and industry trends," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California). Much like BIME, the *VDC Scorecard* has also been privately commercialized through a program called *bimSCORE* (Kam et al. 2013). Using the professional evaluations of three independent *bimSCORE* consultants, it enables organizations to assess their BIM maturity, benchmark their BIM-assisted projects in comparison with industry trends, and advise project team members regarding BIM decision making and investments (Kam et al. 2013).

BIM Quickscan

Likewise, in 2009, the Netherlands Organization for Applied Scientific Research (TNO), developed BIM Quickscan, a benchmarking instrument used to assess the BIM performance of companies executing BIM services in the Netherlands. It scores organizations based on four chapters of criteria, each composed of weighted key performance indicators (KPIs) that are addressed in the form of a multiple choice questionnaire scored by a certified BIM consultant. It is also offered as an online survey called the self-scan, which is freely available to the public (van Berlo et al. 2012).

Building Owner Perspectives on BIM Maturity

Although many of these assessment tools are intended for stakeholders to evaluate themselves and where they stand in terms of BIM implementation, seldom do they address the maturity of building owner organizations as a separate entity nor do they incorporate their specific needs during O&M. Indiana University (IU) is one of the few facility owner organizations to have developed a standard means for evaluating the BIM proficiency of potential designers and contractors on new projects. With the help of a consultant, they developed a BIM proficiency matrix as part of their project team selection process on campus building projects. Designers and contractors are evaluated on the basis of a customized set of eight areas of interest evaluated across four distinct maturity levels. Using a Microsoft Excel template matrix, designers and contractors must provide a description and concrete example of past projects in which they have participated that address the areas of interest. On the basis of their answers, each subcategory is scored by the university and summed for a maximum score of 32 points (IU 2009).

Most similar to the intent of this study was the work of the computer integrated construction (CIC) research program at Penn State University. Their *Facility Owner's Guide*, first published in 2012, provides a template maturity matrix that corresponds to the guide and its suggested execution strategies. The matrix is divided into six key BIM planning elements and further divided into subcategories for evaluation. Owners are encouraged to rate their organization on a maturity scale from 1 to 5 across each of the execution planning elements (CIC 2012).

Chen et al. (2012), in an effort to synthesize some of the BIM maturity research efforts, developed a framework for measuring BIM maturity on the basis of the perceptions of a sample of BIM experts inside and outside of the United States. They determined 27 indices for measuring BIM maturity on the basis of the NBIMS CMM and Succar's BIM maturity matrix (Chen et al. 2012; Dib et al. 2012).

Table 1. Comparison of Six Leading BIM Maturity Evaluation Tools

Parameter	NBIMS CMM (NIBS 2007)	BIME (Succar 2009, 2010; Succar et al. 2013)	BIM proficiency matrix (IU 2009)	BIM Quickscan (van Berlo et al. 2012)	*VDC scorecard/bimSCORE* (C. Kam et al., "The formulation and validation of the VDC scorecard," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California; Kam et al. 2013; C. Kam et al., "The VDC scorecard evaluation of AEC projects and industry trends," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California)	Owner maturity matrix (CIC 2012)
Intended user group	A, E, C, O	A, E, C, O	A, E, C	A, E, C	A, E, C, O	O
Rating context	Evaluates information management on building projects	Evaluates organizations, projects, teams, or individuals	Evaluates designers and contractors' ability to perform BIM services	Evaluates BIM performance level of organizations providing BIM services	Evaluates project BIM performance and maturity	Evaluates owners' maturity of BIM planning strategies
Evaluation style	Self-evaluation	Multiple types of evaluation offered	Free-response Excel input form	External certified evaluator or a free online self-scan assessment	Multiple types of evaluation offered	Self-evaluation
Measurement categories and weightings	11 areas of interest weighted on the basis of importance	Multiple indices with different categories on the basis of the evaluation context	Eight areas of interest that are all weighted equally	Four chapters and 10 different aspects on the basis of weighted KPIs	Four areas across 10 different dimensions and several weighted measures	16 planning elements that are weighted equally
Number of maturity levels	10 maturity levels	Five maturity levels/individual competency levels	Four maturity areas	No maturity levels on the basis of weighted KPIs	Five percentile ranges of increasing innovation	Six maturity levels similar to SEI's CMMI
Criteria used for evaluation	Project documentation and model	Multiple types, including external audit of project documentation, interviews with BIM personnel, and online surveys	Stakeholders' explanation in an Excel template	Quickscan: 50 questions conducted through interviews with BIM personnel; self-scan: an online questionnaire	Excel input form or Web-based dashboard; the full version includes an audit by a CIFE or *bimSCORE* consultant	Internal assessment by key personnel within the organization

Note: A = architecture; C = construction; E = engineering; O = operations.

J. Manage. Eng.

Summary

Table 1 summarizes and compares the most prominent BIM assessment tools proposed thus far on the basis of their intended user groups, evaluation style, rating context, measurement categories, number of maturity levels, and criteria used for evaluation. As shown, most tools have followed the traditional structure of the SEI's CMM, but have been adapted to the building industry and BIM (NIBS 2007; Succar 2010; CIC 2012). Others have approached evaluation from a quantitative benchmarking perspective (van Berlo et al. 2012; C. Kam et al., "The formulation and validation of the VDC scorecard," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California; C. Kam et al., "The VDC scorecard evaluation of AEC projects and industry trends," working paper, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Stanford, California).

One of the greatest benefits of these toolsets has been the establishment of quantitative metrics for comparison. In particular, the NBIMS CMM, BIME, BIM Quickscan, and *VDC Scorecard* have all proven to be useful in the assessment of organizational BIM maturity in and outside of the United States. They have all been validated across a large sample of projects and organizations and have demonstrated repeatable results over an extended period of time. They provide valuable insight on the state of BIM execution across the AECO industry, and the publication of their results has encouraged greater adoption by many stakeholders.

One drawback of several of the tools has been the increasing trend to offer the evaluations for profit because many of the tools are authored by private consulting agencies. One might argue this as a potential shortcoming because by offering full evaluations at a cost to the user, they may limit the sample of the population that is evaluated, leading to biased results and conclusions about the population at large. In addition, the tools tend to be more developed in the areas of organizational maturity evaluation. Very few address evaluation of the model itself or the data contained in the model. Finally, although many of the proposed tools may be used to evaluate owners, only one has been specifically tailored for that user category. The CIC (2012), in their *Facility Owner's Guide*, was the first to address the unique nature of building owners in BIM maturity evaluation. However, little detail was given regarding how the assessment variables were chosen and weighted in their suggested model. This study attempts to expand on their foundation and suggests a different approach to assessment, which incorporates a more inclusive list of variables for evaluation.

Methodology

The procedure used for this research study was executed in three primary phases: comparison, prioritization, and development, with each phase corresponding to a specific research aim. Fig. 1 shows the sequence of the research methodology.

Phase I: Comparison

The first phase of this research involved the compilation of a comprehensive list of variables measured by the existing BIM assessment tools uncovered during a review of literature. A matrix was created to compare the different variables assessed by the NBIMS CMM, BIM maturity matrix, BIM Quickscan, BIM proficiency matrix, *VDC Scorecard*, and CIC Research Program's owner's maturity matrix (Giel and Issa 2013). The list was then categorized into process-driven and product-driven variables and then further grouped on the basis of their semantic similarities. Process-driven variables refer to factors used to evaluate organizational processes. These types of factors are predominantly found in the tools most closely resembling a traditional maturity model used to assess organizations executing BIM (Succar 2010; CIC 2012; van Berlo et al. 2012; IU 2009). Product-driven variables refer to factors used to evaluate an end product or output, such as the virtual building information model itself or a project that used BIM (NIBS 2007; C. Kam et al., "The formulation and validation of the VDC scorecard," working paper, Center for Integrated Facility Engineering,

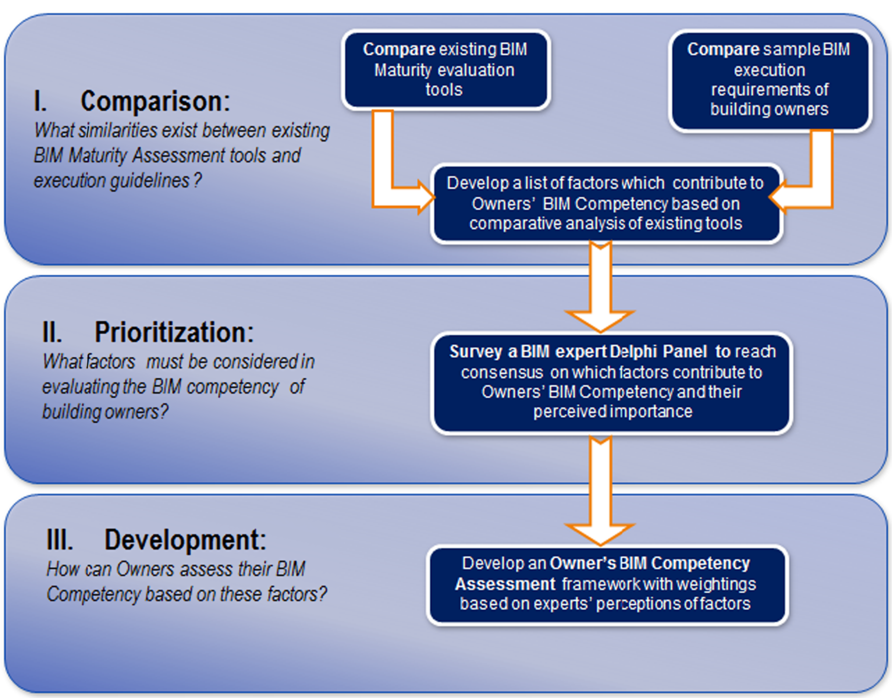

Fig. 1. Research methodology

Department of Civil Engineering, Stanford University, Stanford, California). The purpose of this research phase is to determine a baseline list of factors that could be used to evaluate the BIM competencies of owners and shed light on where potential overlap occurs among the existing tools.

Delphi Analysis

The Delphi technique has been widely adopted among a number of different research disciplines. Hallowell and Gambatese (2010) identified seven studies in the field of construction engineering and management (CEM) published in peer reviewed journals in the last decade that have used the Delphi technique as a primary or secondary research methodology. In addition, Skulmoski et al. (2007) summarized more than nine published studies in the field of information systems (IS)/information technology (IT) that have implemented it.

The Delphi technique is often useful when there is incomplete knowledge about a problem, when the problem addressed does not lend itself to analytical quantitative techniques, and/or when collective problem solving may be useful (Skulmoski et al. 2007). Because of the novelty of using BIM during O&M and the lack of concrete uses by building owners thus far, this technique was chosen as a means for the development and prioritization of competency factors related to building owners' execution of BIM in Phase II. The four most notable characteristics of the Delphi technique are anonymity, iteration, controlled feedback, and statistical aggregation of group responses to achieve consensus (Rowe and Wright 1999). Expert panels can range from 3 to 80 members, and anywhere from two to six rounds can be conducted. However, Hallowell and Gambatese (2010) suggest three rounds of at least 8–12 panelists on the basis of their review of CEM Delphi applications.

Phase II: Prioritization

Over a period of 5 months, a BIM expert panel was assembled and surveyed to determine the leading factors most useful for the evaluation of building owners' BIM competency. A total of five separate respondent categories were targeted, including architects/engineers, contractors, owners, consultants, and academics. All of the participants satisfied at least one of the following three selection criteria:

1. Possess at least 5 years of BIM experience working with an architectural firm, construction management firm, engineering, or specialty consulting firm and have personally worked on at least five projects in which BIM deliverables were exchanged at critical lifecycle phases. They were required to have had experience working with owners who require BIM deliverables in addition to their own organizational BIM experience.
2. Works for an owner organization that had required BIM for a period of 6 months or more and has had direct experience working with BIM deliverables on a minimum of five projects. A BIM manager within such an organization would be the preferred panelist.
3. Conducts research in the BIM maturity or facility management domain and satisfies at least four of the criteria outlined by Hallowell and Gambatese (2010) in qualifying a CEM expert from academia.

These criteria were chosen on the basis of many of the published statistics that have been outlined in industry surveys in recent years [McGraw Hill Construction 2012, 2014; Becerik-Gerber et al. 2012; International Institute for Sustainable Laboratories (I^2SL); buildingSMART Alliance (BSA); International Facility Management Association (IFMA) Research and Development Council 2013]. BIM adoption increased substantially after the first publication of the NBIMS in 2007. Because this study was conducted in 2012, a metric of 5 years of BIM experience was used as an indicator for qualifying BIM service providers. This ensured that those participating in the panel represented organizations with a substantial BIM portfolio. A survey conducted before the research study (Mayo et al. 2014) and a previous literature review showed a lack of qualified experts in the building owner organization category. Therefore, qualifications for participants in that user category were relaxed to 6 months, with formal BIM requirements, to achieve a diverse sample of experts.

Solicitation for participants for the BIM expert panel were sent through e-mail to VDC/BIM managers employed by the Engineering News-Record's (ENR's) 2012 top 500 design firms (Tulacz 2012b) and top 400 contractors (Tulacz 2012a), members of the Florida chapter of the Construction Owners Association of America (COAA), and the BIM for Owners group on LinkedIn. Additionally, the research proposal was physically presented at the 2012 campus facilities management (FM) technology association (CFTA) conference and the 2013 BSA Building Innovation Conference and Expo. Using the criteria previously outlined, a 10-question survey was administered to determine the qualifications and BIM experience level of all potential participants. All eligible respondents were then formally invited to participate.

The selected expert panel participated in three rounds of anonymous electronic questionnaires that were delivered through e-mail over a period of 3 months. Using a three-point Likert scale, participants were asked to suggest and rate the perceived importance of a list of BIM competency factors derived originally from the comparison phase of this research (Giel and Issa 2013).

Similar to Al-Hajri et al. (2012) and Caldwell (2007), the interquartile range (IQR) was used as the primary means to confirm suitable agreement on the perceived importance of each BIM competency factor. Consensus was considered to be reached for each factor receiving an IQR < 2. Additionally, on the basis of the recommendations of Scheibe et al. (1975), the percentage change in the mean rating for each factor between rounds was used as an additional method to confirm stabilization of opinion, which is the primary driver for determining that no more survey rounds are required.

Phase III: Development

As a product of the prioritization phase, a total of 66 critical BIM competency factors were identified and prioritized in order of their perceived mean importance by the panel. On the basis of these results, the subsequent phase involved the conversion of all Likert scale importance ratings for each factor into a BIM competency assessment framework for owners to evaluate themselves with. The prioritization of variables was replicated in the assessment framework using a weighting system on the basis of the work of Xia and Chan (2012). The mean importance rating for each BIM competency factor received in the final Delphi round was divided by the total sum of all factors' final mean importance ratings. Eq. (1) summarizes how the weighting factors were determined

$$W_i = \frac{\mu_i}{\sum_{i=1}^{n} \mu_i} \quad (1)$$

where W_i represents the weighted proportion of the assessment score used for a particular BIM competency factor; μ_i represents the mean importance rating of a particular BIM competency factor; and $\sum \mu_i$ represents the summation of all mean importance ratings evaluated.

Each competency factor was addressed in the final assessment tool in the form of one or more multiple choice questions. Responses to each question were then weighted using Eq. (1).

Results

Phase I

A total of 60 unique variables were identified as possible factors for evaluating owners' BIM competencies during the review of the literature. Giel and Issa (2013) compared the semantic similarities among each evaluation variable described in the NBIMS CMM, BIM maturity matrix, BIM Quickscan, BIM proficiency matrix, *VDC Scorecard*, and owners' maturity matrix and determined that there was significant overlap among the existing tools.

Of the 60 factors that were identified, 29 were considered product-driven variables and 31 were considered to be process-driven variables. A total of 13 factors (22% of the total) were referenced by three or more of the six assessment tools. Further analysis also revealed that there was greater emphasis placed on process-driven variables than on product-driven variables among the existing tools. Of the 13 factors, 10 (76%) common to three or more assessment tools were identified as process variables.

In addition to the original 60 factors identified by previous research efforts, eight additional variables were added as possible areas for evaluation of building owners' BIM competency. The final product of this research phase was the creation of an exhaustive list of 68 factors, which served as the basis for the preliminary Delphi round in Phase II.

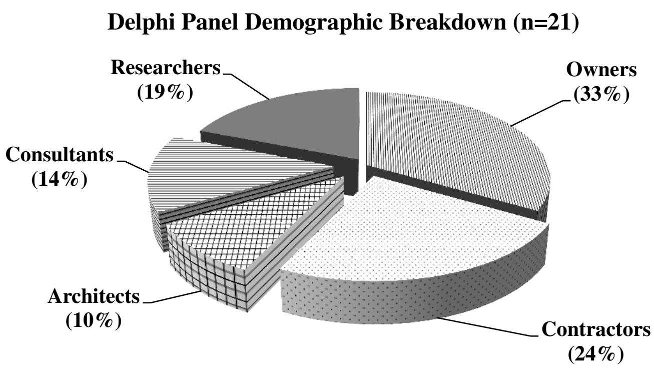

Fig. 2. Composition of Delphi panel by respondent category

Phase II

Panel Demographics

A total of 21 qualified BIM experts were identified for the Delphi panel, representing many different perspectives within the AECO industry. Fig. 2 shows the proportion of respondents within each major respondent category. As shown, the panel contained seven representatives from building owner organizations, five representatives from construction management organizations, three representatives from BIM consulting firms, two representatives from architectural firms, and four researchers with experience in the FM and BIM maturity domain.

Table 2 lists the qualifications of those expert panel members considered to be BIM service providers to owners. They represented architects, construction managers, and consultants. As shown, the two experts on the panel denoted by the architect category represented design firms with anywhere between 5 and 7 years of organizational experience producing BIM deliverables and personal BIM management experience on 5–10 BIM-assisted projects, many of which included BIM requirements set forth by owners. The five experts on the panel denoted by the contractor

Table 2. Summary of the Qualifications of All BIM Experts in the Service Provider Category

Stakeholder type	Number of years providing BIM services as an organization	Number of projects assisted by BIM as an organization	Number of BIM projects with personal experience	Number of BIM projects with personal experience incorporating owner requirements
Architect	7	1,000	10	2
Architect	5	N/A	5	3
Contractor	7	247	50	16
Contractor	10	100	12	4
Contractor	7	100	40	5
Contractor	7	200	8	6
Contractor	N/A	5	5	3
Consultant	7	20	20	6
Consultant	5	60	60	10
Consultant	N/A	N/A	N/A	N/A

Table 3. Summary of the Qualifications of All Experts in the Owner Category

Organization type	Number of years executing BIM as an organization	Number of projects assisted by BIM as an organization	Number of BIM projects with personal experience	Percentage of projects that require BIM
Healthcare provider	0.5	7	5	All contracts > $5 million
University	5	20	15	100%
University	3	5	5	All large contracts
University	2	7	1	N/A
University	6	22	22	100%
Government	7	10	10	N/A
Military	2	100	8	All large contracts

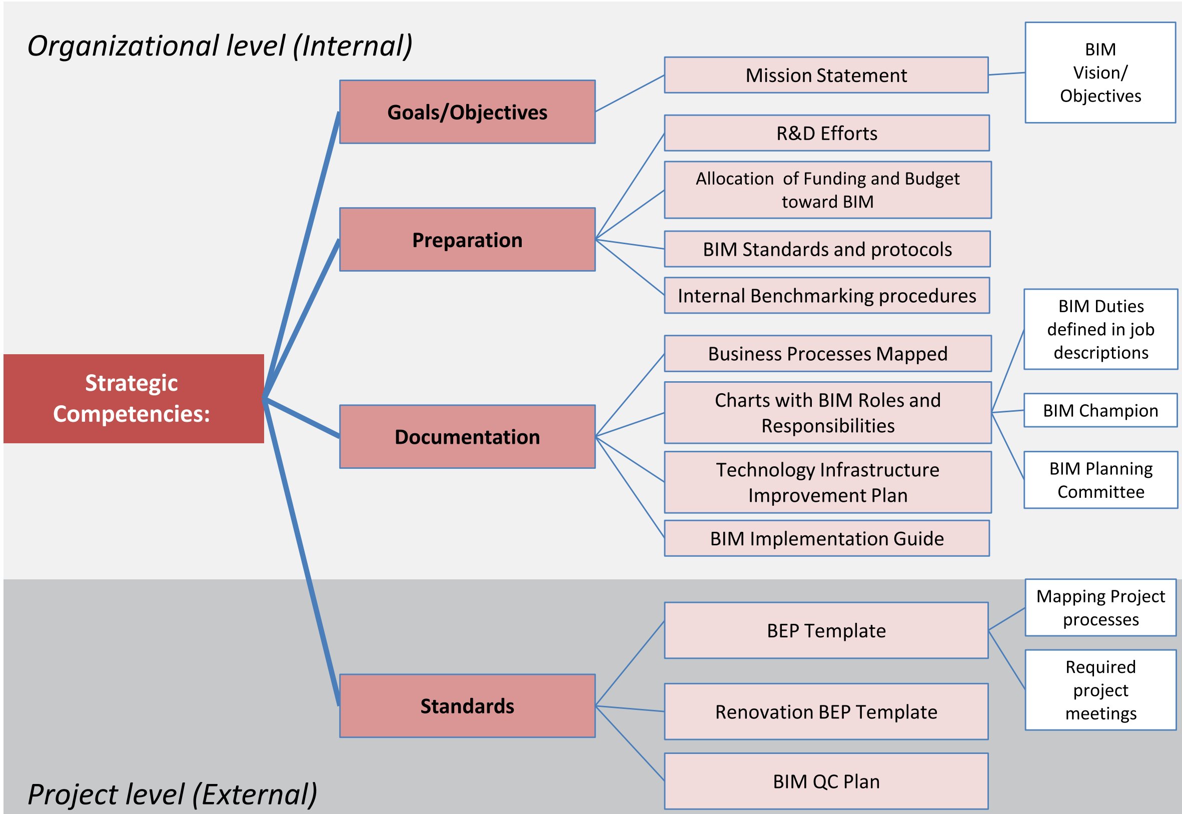

Fig. 3. Strategic competencies

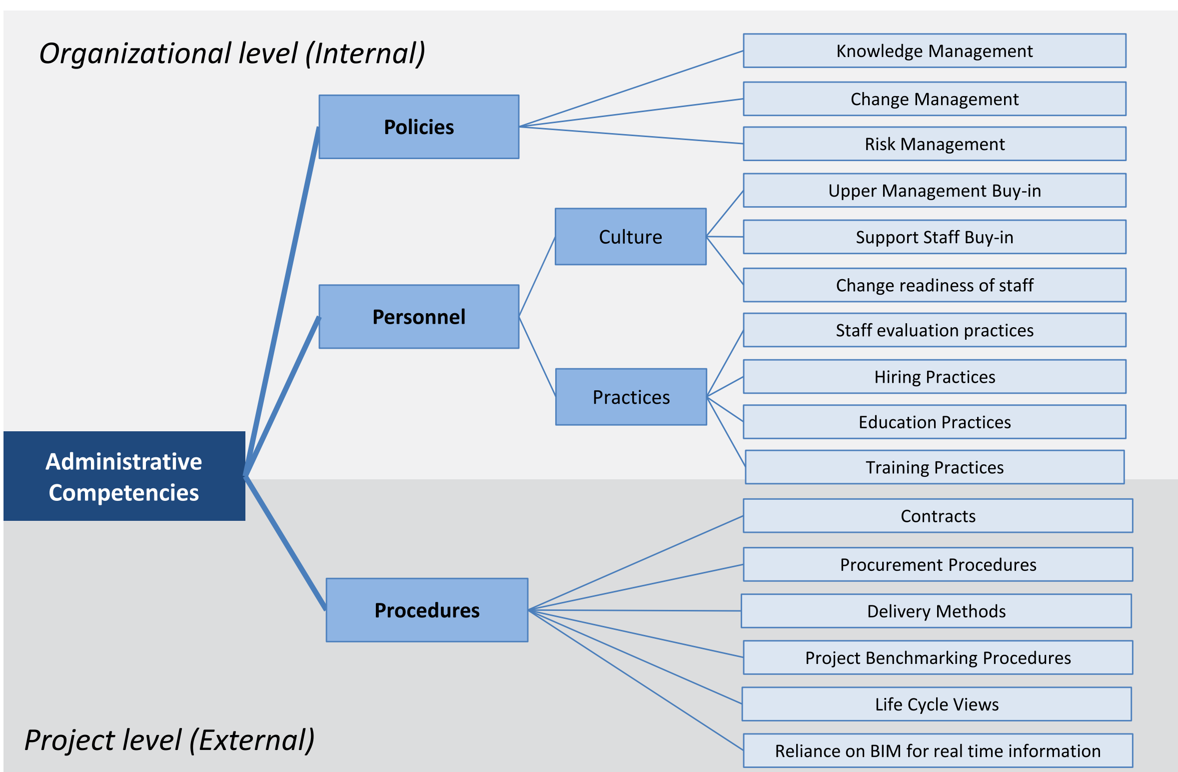

Fig. 4. Administrative competencies

category represented large construction management firms with anywhere between 7 and 10 years of organizational experience producing BIM deliverables and personal BIM management experience having worked on anywhere from 8 to 50 BIM-assisted projects, many of which included BIM requirements set forth by owners. Finally, the three experts on the panel in the consultant category represented BIM consulting/service providers who deliver strategic BIM consulting and production services to AECO clients. The experts in this category represented firms with 5–7 years of organizational experience producing BIM deliverables and research. They also indicated having personal BIM experience working on anywhere from 5 to 60 BIM-assisted projects in their career portfolio.

Table 3 shows the qualifications of the panel experts representing the owners' category. The seven experts in this category represented two primary roles within their respective organizations, either as an owners' representative utilized primarily for construction administration or as an operator/custodian of existing facilities utilized primarily after construction handover. As shown, the panel members in this category represented the interests of four university organizations, one healthcare facility provider, one federal entity, and one military entity. These experts represented anywhere from 6 months to 7 years of organizational experience dealing with BIM deliverables and had personal BIM management experience working on anywhere from 1 to 22 BIM-assisted projects. Of the seven experts, five represented organizations that at that time required that BIM be used on all large contracts.

The final four experts belonged to the researcher category and represented the interests of academic and professional organizations with a vested knowledge in BIM maturity evaluation and facility management applications. Many of the participants in this category held professional memberships and licenses, were authors of several leading scholarly publications on BIM, and had advanced degrees in the AECO disciplines. They had between 2 and 9 years of experience in this research domain and were all active members of the BSA at the time of the study.

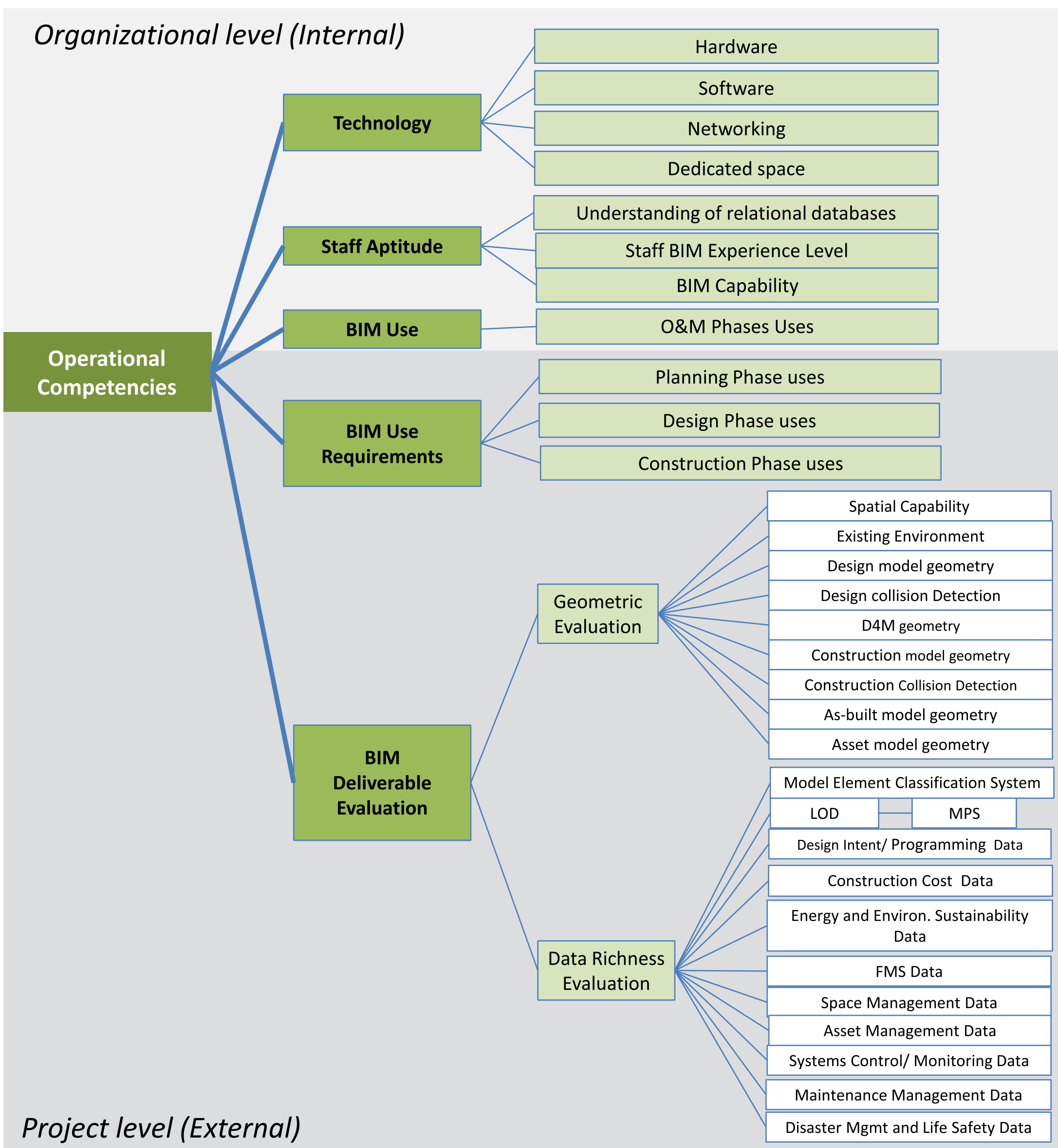

Fig. 5. Operational competencies

Round 1

The Round 1 (R1) questionnaire was designed as a free response survey to collect the panelists' perceptions about the preliminary list of 68 BIM maturity variables that were developed from Phase I of the research study (Giel and Issa 2013). The R1 allowed the respondents to suggest additional factors applicable to the evaluation of building owners' BIM competency and remove any factors from the list that they felt were not relevant. All factors selected by less than 50% of the expert panel in R1 were removed from the Round 2 (R2) survey.

On completion of R1, six competency factors were eliminated and four new factors were suggested as additional variables for evaluation. The six factors selected by less than 50% of the panel, which were removed after R1, were (1) the ratio of an owner's workforce with documented BIM experience; (2) the presence of a reward system for project team members executing BIM; (3) having documented information requirements for material procurement; (4) having documented information requirements for construction scheduling; (5) having documented requirements for open BIM; and (6) having documented geometric requirements for fabrication models. The four newly suggested factors contributed by the panel for R2 were (1) staff understanding of relational databases; (2) energy and environmental sustainability data requirement specifications; (3) geometric evaluation of design for maintenance review (D4M) aspects; and (4) geometric evaluation of the asset model.

A major contribution of Round 1 was the creation of the logical framework behind the proposed assessment tool, which would serve as the basis of the scorecard to be created in Phase III. On the basis of suggestions made by the expert panel, the competency factors were grouped into three major categories on the basis of semantic similarities, including strategic competencies, administrative competencies, and operational competencies.

Strategic competencies included factors that affect an owner organization's ability to plan and develop a course of action for its BIM execution efforts. Within the framework, these factors were further subdivided into the categories goals and objectives, preparation, documentation, and project standards. Fig. 3 shows the 18 factors that make up the strategic competency area in the evaluation framework and how they were categorized.

Administrative competencies included factors that affect the ability of an owner organization to manage resources and meet the desired goals that are related to its internal BIM execution efforts. These were further subdivided into policies, personnel, and project procedures. Fig. 4 shows the 16 BIM competency factors that make up the administrative competency area in the evaluation framework and how they were categorized.

Finally, the operational competencies included factors that affect the ability of an owner organization to execute BIM at the organizational and project level. Factors in this area were subdivided into the categories technology, staff aptitude, organizational BIM use during O&M, BIM use requirements, and BIM deliverable evaluation. A large number of the factors in this area were related to how an owner evaluates the building information model. For this reason, BIM deliverable evaluation was further grouped into factors related to geometric evaluation and factors related to data richness evaluation. Fig. 5 shows the 32 competency factors that make up the operational competency area within the evaluation framework.

Round 2

The R2 questionnaire was designed to validate the newly consolidated list of 66 competency factors identified in Round 1. The participants were asked to rate the importance of each relevant factor on a three-point Likert scale, with a score of 1 corresponding to the rating of not important, a score of 2 corresponding to a rating of important, and a score of 3 corresponding to a rating of very important.

Table 4. Factors Reaching Early Consensus in R2

Competency factors	First quartile (Q1)	Second quartile (Q2)	Third quartile (Q3)	IQR
Strategic competencies				
Organizational mission statement	3	3	3	0
BIM vision and objectives	3	3	3	0
Research and design efforts	2	2	2	0
BIM job duties	2	2	2	0
BIM champion	3	3	3	0
Technology improvement plan	2	2	2	0
Administrative competencies				
BIM hiring practices for new staff	2	2	2	0
Evaluation practices for BIM staff	2	2	2	0
BIM education practices	3	3	3	0
BIM training practices	3	3	3	0
Upper management buy-in	3	3	3	0
Reliance on BIM for real-time information (timeliness of response)	2	2	2	0
Operational competencies				
Staff BIM experience	2	2	2	0
Planning phase uses	2	2	2	0
Energy and environmental sustainability data requirements	2	2	2	0
Model progression specification	2	2	2	0
Construction clash detection	3	3	3	0
As-built model geometry	3	3	3	0

Consensus among the panel was considered suitably achieved for any factor that received an importance rating IQR of 0. As a result of R2, 18 factors received suitable consensus among the panel early on and were removed from the Round 3 (R3) survey. This included six strategic competency factors, six administrative competency factors, and six operational competency factors. Table 4 lists the 18 factors that reached suitable consensus by the panel in Round 2.

Round 3

Finally, the R3 questionnaire was designed to give participants the opportunity to reconsider their answers on the basis of the anonymous R2 responses for the remaining 48 competency factors in the framework. The R2 mean and median importance ratings awarded for each remaining factor were disclosed to the panelists and the cumulative frequency of rating responses for each factor to provide controlled feedback.

On the basis of the suggestions of Scheibe et al. (1975), stabilization of opinion between rounds was evaluated using the percentage change in mean importance rating between Rounds 2 and 3 for each competency factor. The percentage change in mean remained below 15% for all but one of the final 48 factors evaluated, and therefore it was concluded that Round 3 was the final survey round required.

The level of agreement among the Delphi panel varied across the different BIM competency factors that were evaluated. However, overall, a relatively high consensus was reached among importance ratings for the majority of factors. As shown in Table 5, 61% (40) of the total 66 factors had an IQR value off less than 1 after Round 3 was complete, indicating high agreement and 38% (25) received an average level of agreement. Data richness evaluation of disaster management requirements had an IQR that remained at a value of 2 in Round 3, indicating higher dispersion among the panel's responses. For that reason, it was removed

Table 5. Level of Agreement among the Panel

Consensus level	Criteria	Number of factors	Percentage of total
High agreement	$0 < IQR < 1$	40	61
Average agreement	$1 < IQR < 2$	25	38
Low agreement	$IQR = 2$	1	1
Total	—	66	100

from the proposed BIM competency assessment tool weightings discussed in Phase III.

Table 6 summarizes the median importance (Q2) ratings and IQR indicated by the panel responses obtained in Rounds 2 and 3 for all 40 factors whose importance ratings reached a high level of consensus ($IQR < 1$). Factors with an IQR of 0 in Round 2 were removed in R3, but are shown as part of the comprehensive list for comparison purposes. The competency factors are listed in descending order of their median values in R3 and then by competency area for ease of readability.

Similarly, Table 7 summarizes the 25 BIM competency factors that reached an average level of agreement among the panel with an IQR of 1. As shown, there was not a substantial change between the median and IQR values between Rounds 2 and 3 for those competency factors, which also indicates stabilization of opinion by the panel.

The final contribution from this research phase was the relative prioritization of the 66 BIM competency factors that are used to inform the weighting distribution conducted in Phase III. Fig. 6 summarizes the prioritization of the BIM competency factors that were assessed during Phase II of the research study. They are sorted in order of the mean importance rating.

Phase III

After applying weightings to each of the individual BIM competency factors, excluding data richness evaluation of disaster management requirements, the relative ranks and weightings of each competency area and category were assessed. Table 8 summarizes the final weighting factors and corresponding ranks that were

Table 6. Summary of Competency Factor Ratings with High Agreement

BIM competency area	Factors	$R2(n = 21)$		$R3(n = 21)$	
		Median	IQR	Median	IQR
Administrative	BIM education strategies	3	0	—	—
Administrative	BIM training strategies	3	0	—	—
Administrative	Upper management buy-in	3	0	—	—
Administrative	Contracts that address BIM	3	1	3	0
Operational	Design phase uses	3	1	3	0
Operational	Construction phase uses	3	1	3	0
Operational	Level of development (LOD)	3	1	3	0
Operational	Facility management system data transfer	3	1	3	0
Operational	Design collision detection	3	1	3	0
Operational	Design for maintenance geometry	3	1	3	0
Operational	Construction model geometry	3	1	3	0
Operational	Construction clash detection	3	0	—	—
Operational	As-built model geometry	3	0	—	—
Strategic	Mission statement	3	0	—	—
Strategic	BIM vision	3	0	—	—
Strategic	BIM champion	3	0	—	—
Strategic	Allocation of budget toward BIM	3	1	3	0
Strategic	BIM execution plan (BEP) standard	3	1	3	0
Strategic	Required project BIM meetings	3	1	3	0
Strategic	QC plan for checking BIM deliverables	3	1	3	0
Administrative	Risk management strategies	2	1	2	0
Administrative	BIM hiring strategies for new staff	2	0	—	—
Administrative	Evaluation strategies for existing staff	2	0	—	—
Administrative	BIM procurement strategies	2	1	2	0
Administrative	Project benchmarking strategies	2	1	2	0
Administrative	Reliance on BIM for real-time information	2	0	—	—
Operational	Software standards	2	1	2	0
Operational	Networking services	2	1	2	0
Operational	Staff BIM experience	2	0	—	—
Operational	Planning phase uses	2	0	—	—
Operational	Model progression specification	2	0	—	—
Operational	Design/programming data	2	1	2	0
Operational	Construction cost data	2	1	2	0
Operational	Energy and environmental sustainability data	2	0	—	—
Operational	Systems control and monitoring data	2	1	2	0
Strategic	Research and design strategies	2	0	—	—
Strategic	Organizational job charts	2	1	2	0
Strategic	BIM job duties	2	0	—	—
Strategic	Technology improvement plan	2	0	—	—
Strategic	Requirement for project process maps	2	1	2	0
Operational	Systems control and monitoring data	2	1	2	0

Table 7. Summary of Competency Factor Ratings with Average Agreement

BIM competency area	Factors	$R2(n = 21)$ Median	$R2(n = 21)$ IQR	$R3(n = 21)$ Median	$R3(n = 21)$ IQR
Administrative	Delivery methods that address BIM	3	1	3	1
Operational	O&M phase uses	3	1	3	1
Operational	Model element classification	3	1	3	1
Operational	Space management data requirements	3	1	3	1
Operational	Asset management data requirements	3	1	3	1
Strategic	Organizational business process maps	3	1	3	1
Strategic	BIM planning team	3	1	3	1
Strategic	BIM implementation guide	3	1	3	1
Administrative	Change management strategies	2	1	3	1
Operational	Maintenance management data requirements	2	1	3	1
Operational	Asset model geometry	2	1	3	1
Strategic	BIM standards and protocols	2	1	3	1
Strategic	Renovation BEP	2	1	3	1
Strategic	Internal benchmarking strategies	3	1	2	1
Administrative	Knowledge management strategies	2	1	2	1
Administrative	Support staff buy-in	2	1	2	1
Administrative	Organizational change readiness	2	1	2	1
Administrative	Lifecycle views	2	1	2	1
Operational	Hardware standards	2	1	2	1
Operational	Dedicated space configured with technology for collaboration	2	1	2	1
Operational	Understanding of relational databases	2	1	2	1
Operational	BIM capability	2	1	2	1
Operational	Spatial capability	2	1	2	1
Operational	Existing environment integration	2	1	2	1
Operational	Design model geometry	2	1	2	1

derived for each BIM competency area in the assessment framework using Eq. (1). For example, operational competency factors represent 47% of the total assessment framework, strategic competency factors make up 29% of the framework, and administrative competency factors make up 24%. Because operational competencies made up the largest proportion of factors in the framework, they were consequently weighted highest in the framework as shown.

Fig. 7 summarizes the full BIM competency assessment framework and how each of the individual competency categories are further parsed within each BIM competency area on the basis of the weighting calculations that were conducted. As shown, BIM deliverable evaluation comprises 68% of the total operational competency score (TOCS) in the proposed framework. The BIM use requirements and technology make up 11 and 10%, followed by staff aptitude (representing 8%) and organizational BIM use representing 4% of the TOCS evaluation in the framework. Within the strategic competency area, documentation comprises 37% of the evaluation, followed by project standards, preparation, and goals/objective representing 29, 22, and 12%, respectively, of the total strategic competency score (TSCS). Finally, within the administrative competencies, personnel: culture and practices comprise 44% of the evaluation, followed by project procedures and policies representing 38 and 18% of the total administrative competency score (TACS).

On the basis of this framework, an assessment tool was created. The owner's BIM competency assessment tool (BIMCAT) is a self-assessment scorecard designed to be completed by any person in a management position within an owner organization having relevant knowledge about the organization's BIM execution efforts. The tool consists of 124 total questions, for a maximum total score of 1,200 points. Similar to the CMM-I model defined by SEI (2011) and the suggestions of the CIC Research Program (2012), the five most frequently cited maturity levels are proposed for inclusion in the BIMCAT. Table 9 describes the competency levels defined for each score range assigned in the BIMCAT. For example, any score below 200 would represent BIM Competency Level 0, indicating that no significant effort has been made toward BIM execution by an owner organization. In contrast, scores greater than 1,000 points would result in BIM Competency Level 5, indicating the presence in an owner organization of optimized and quantitatively measured processes related to BIM execution.

Discussion

There were several important findings derived from the comparison and prioritization phase of this research study. Perhaps the most relevant finding from the prioritization phase was the experts' perception of the significance of upper management buy-in and having a documented quality control (QC) plan for checking BIM deliverables. This suggests that a detailed methodology must be developed to aid owners in conducting BIM deliverable quality assessments at different points of the building lifecycle. There is also a strong need to develop a framework for educating existing FM professionals about BIM processes and technology. This is a cultural change that must take place to help FM staff reap the benefits of many of the operational competencies. More importantly, there is a need to truly understand the information needs of FM professionals before requirements documentation are refined.

The most important outcome from Round 1 of the Delphi phase was the elimination of six factors originally included in the comprehensive list. Less than 50% of experts felt that having an adequate proportion of the owners' staff with BIM responsibilities was relevant to the assessment of their competency. This suggests the perception that BIM management roles are not required for a large portion of staff within owner organizations. In addition, the presence of a reward system for successful BIM execution efforts was not selected to be relevant to the owner's BIM competency in

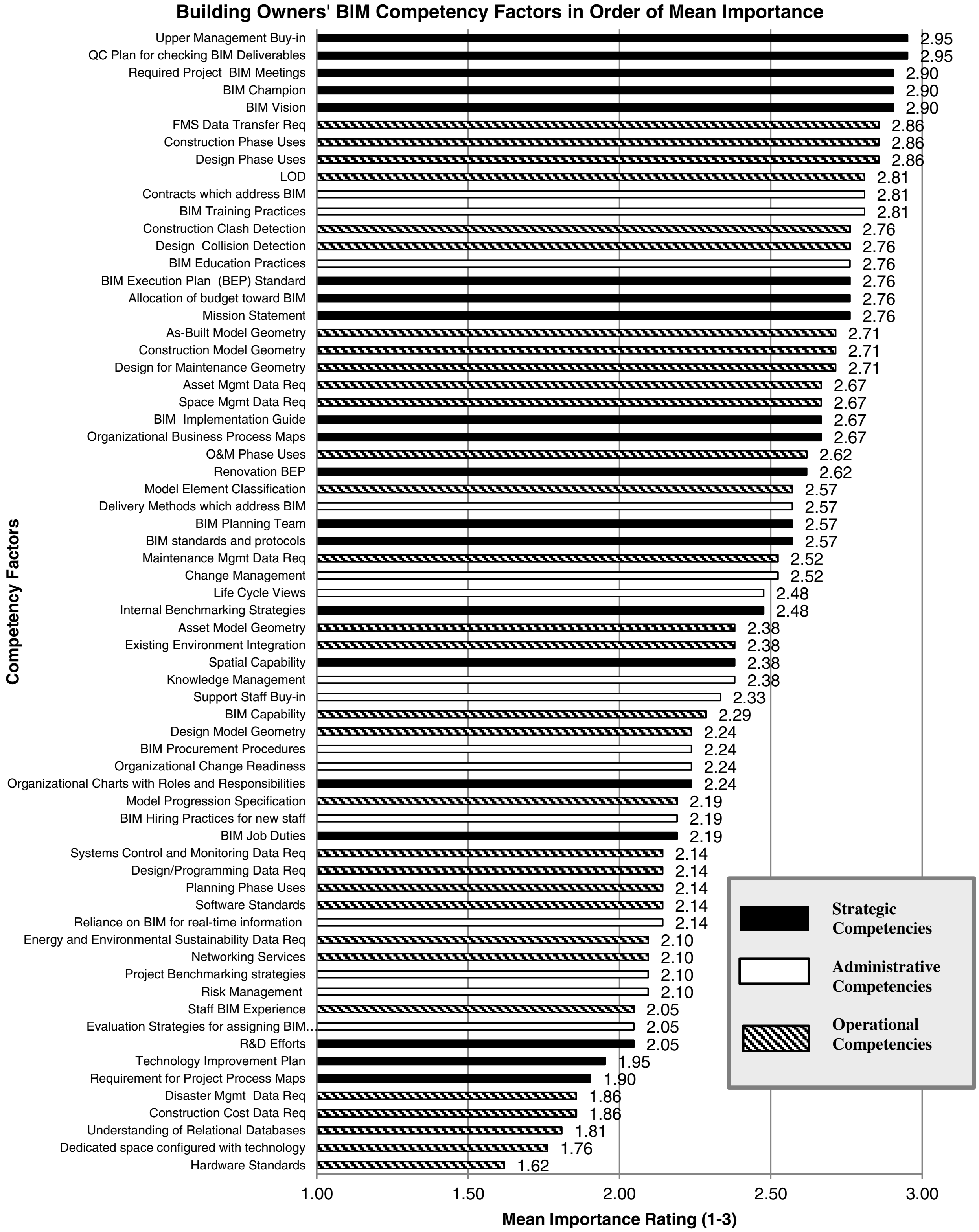

Fig. 6. Final mean importance ratings for all factors in order of relevance

Table 8. Weightings Derived for BIM Competency Areas

BIM competency area	Rank	Assessment weighting
Operational competencies	1	0.47
Strategic competencies	2	0.29
Administrative competencies	3	0.24

Round 1. Moreover, data specifications related to material procurement and construction scheduling and geometric evaluation of the fabrication model were factors that did not make the final prioritized list of necessary BIM competencies for owners. Finally, perhaps the most interesting finding from Round 1 was the exclusion of open BIM standards from the final BIM competency list. Only 43% of the expert panel perceived it to be relevant to the evaluation

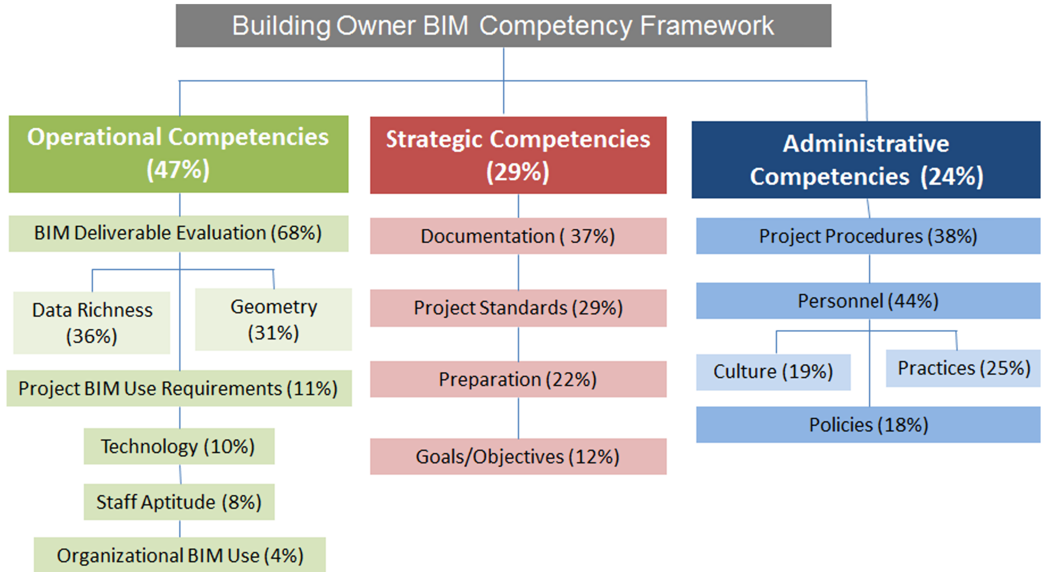

Fig. 7. BIMCAT framework

of the owners' BIM competency. This suggests that open standards have either not matured enough to be readily useful to owners or that owners are not technically capable of utilizing an IFC-compliant data model at this time.

There were 18 factors within the final 66 competencies evaluated for which the panel reached minimum agreement early in Round 2. Table 10 summarizes these factors. It appears that the panel reached consensus regarding factors within the top seven and bottom five ranks in R2. This suggests that many of the factors that were more difficult for experts to prioritize fell between the important and very important rating categories.

In Round 3, the most relevant finding was the change in the perceptions of the panel regarding factors like the QC plan for BIM deliverables, change management, and design phase uses for BIM. Additionally, the panel's perceptions regarding the importance of risk management increased substantially between Rounds 2 and 3. Finally, the exclusion of data specifications regarding disaster management in the final prioritization of the BIM competency factors was another key outcome from Round 3. The final average importance rating received for that factor was 1.86.

Table 9. BIMCAT Competency Levels

BIM competency level	Name	Score range
Level 0	Nonexistent	0–200
Level 1	Initialized	200–400
Level 2	Managed	400–600
Level 3	Defined	600–800
Level 4	Quantitatively managed	800–1,000
Level 5	Optimizing	1,000–1,200

Table 10. Factors Reaching Early Consensus by the Panel

Factors	Mean	Median	Overall rank
Upper management buy-in	2.95	3	1
BIM vision and objectives	2.90	3	2
BIM champion	2.90	3	2
BIM training practices	2.81	3	4
Construction clash detection evaluation	2.76	3	5
BIM education practices	2.76	3	5
Organizational mission statement	2.76	3	5
As-built model geometry evaluation	2.71	3	6
BIM job duties	2.19	2	15
BIM hiring practices	2.19	2	15
Model progression specifications	2.19	2	15
Timeliness/response	2.14	2	16
Planning phase uses	2.14	2	16
Energy and environmental sustainability data specifications	2.10	2	17
R&D efforts	2.05	2	18
BIM evaluation of existing staff	2.05	2	18
BIM experience of staff	2.05	2	18
Technology improvement plan	1.95	2	19

Conclusions

Several researchers have attempted to assess and quantify the maturity of BIM development in the AECO industry; however, few have addressed the uniqueness of building owners who play a critical role in achieving lifecycle use of BIM. This study illustrates multiple areas for evaluating the BIM competency of building owners and proposes a customized framework for them to perform self-assessments of their organizations on the basis of the key perceptions of 21 prominent BIM experts from several diverse backgrounds.

Although owners perceive the great potential value of utilizing BIM, many still feel uncertain about how and where to begin implementing it (McGraw Hill Construction 2012). The BIMCAT serves to provide owners with guidance in establishing a baseline of where their organization stands and possible areas for improvement. The results of this assessment may aid facility owners in expanding their technical knowledge, refining their BIM requirements during design and construction, and finally improving the efficiency of their postconstruction operations.

On the basis of these findings, future researchers can gain insight into the common pitfalls preventing widespread owner adoption of BIM and propose possible solutions. Furthermore, the assessment framework can also be used to collect metrics regarding the state of BIM execution as a whole. Similar to the efforts of CIFE (2013) and Sebastian and van Berlo (2010), the BIMCAT will offer more detailed insight into what owners need and expect from BIM, thereby encouraging greater BIM maturity among other stakeholder types.

The next phase of this study will have to validate the proposed tool across a larger sample of owners in various industries. Another area of further research would be to develop a quality assessment procedure to assist owners in evaluating the BIM deliverables they receive from contractors and designers. Although the importance of requirements and the proper documentation are strongly emphasized in the BIMCAT, developing a procedure for how to check the quality, accuracy, and completeness of a building information model will benefit owners with little technical knowledge, particularly organizations scoring low in the staff aptitude, technology, and personnel categories.

References

Al-Hajri, H., Rezgui, Y., Wilson, I., and Marks, A. (2012). "Using Delphi and AHP in information systems development methodologies." *Computing in civil engineering*, R. R. Issa and I. Flood, eds., ASCE, Reston, VA, 229–236.

Arif, M., Egbu, C., Alom, O., and Khalfan, M. (2009). "Measuring knowledge retention: A case study of a construction consultancy in the UAE." *Eng. Constr. Archit. Manage.*, 16(1), 92–108.

Becerik-Gerber, B., Jazizadeh, F., Li, N., and Clis, G. (2012). "Application areas and data requirements for BIM-enabled facilities management." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000433, 431–442.

Caldwell, C. (2007). "School counselor performance evaluation: A Delphi study to determine content and procedure for a model instrument." Ph.D. dissertation, Texas A&M Univ., San Antonio.

Chen, Y., Dib, H., and Cox, R. F. (2012). "A framework for measuring building information modeling maturity in construction projects." *Proc., 14th Int. Conf. on Computing in Civil and Building Engineering*, V. Telichenko, A. Volkov, and I. Bilchuk, eds., ICCCBE, Moscow.

CIC (Computer Integrated Construction Research Program). (2012). "BIM planning guide for facility owners." Pennsylvania State Univ., University Park, PA.

CIFE. (2013). "CIFE VDC scorecard and BIM scorecard." ⟨http://cifevdc.weebly.com⟩.

Crosby, P. (1979). *Quality is free: The art of making quality certain*, McGraw-Hill Book Company, New York.

Dib, H., Chen, Y., and Cox, R. (2012). "A framework for measuring building information modeling maturity based on perception of practitioners and academics outside the USA." *Proc., 29th Int. Conf. on Applications of IT in the AEC Industry, CIB W078*, R. Issa and C. Issa, eds., Beirut, Lebanon.

Giel, B., and Issa, R. R. A. (2013). "Synthesis of existing BIM maturity toolsets to evaluate building owners." *Computing in civil engineering*, I. Britakis, S. H. Lee, and B. Becerik-Gerber, eds., ASCE, Reston, VA.

Hallowell, M., and Gambatese, J. (2010). "Qualitative research: Application of the Delphi method to CEM research." *J. Constr. Eng. Manage.*, 10.1061/(ASCE)CO.1943-7862.0000137, 99–107.

I^{2}SL (International Institute for Sustainable Laboratories), BSA (buildingSMART Alliance), and IFMA (International Facility Management Association) Research and Development Council. (2013). "BIM for facility management survey." *Proc., buildingSMARTAlliance Conf. Integrating BIM: Moving the Industry Forward*, National Institute of Building Sciences (NIBS), Washington, DC.

IU (Indiana University). (2009). "Building information modeling (BIM) guidelines and standards for architects, engineers, and contractors." ⟨http://www.indiana.edu/~uao/iubim.html⟩ (Sep. 20, 2012).

Kam, C., Rinella, T., and Oldfield, J. (2013). "Using objectified measures to realize the promise of BIM." *J. Natl. Inst. Build. Sci.*, 1(1), 14–18.

Kaplan, R. S., and Norton, D. P. (1992). "The balanced scorecard: Measures that drive performance." *Har. Bus. Rev.*, 70(1), 71–79.

Khalfan, M., Anumba, C., and Carrillo, P. (2001). "Development of a readiness assessment model for concurrent engineering in construction." *Benchmarking*, 8(3), 223–239.

Khoshgoftar, M., and Osman, O. (2009). "Comparison of maturity models." *Proc., 2nd IEEE Int. Conf. on Computer Science and Technology*, IEEE, New York, 297–301.

Kwak, Y., and Ibbs, W. (2002). "Project management process maturity (PM)2 model." *J. Manage. Eng.*, 10.1061/(ASCE)0742-597X(2002)18:3(150), 150–155.

Lockamy, A., and McCormick, K. (2004). "The development of a supply chain management process maturity model using the concepts of business process orientation." *Supply Chain Manage. Int. J.*, 9(4), 272–278.

Mayo, G., Giel, B., and Issa, R. R. A. (2014). "BIM use and requirements among building owners." *Computing in civil engineering*, R. R. A. Issa and I. Flood, eds., ASCE, Reston, VA.

McCuen, T., Suermann, P., and Krogulecki, M. (2012). "Evaluating award-winning BIM projects using the national building information model standard capability maturity model." *J. Manage. Eng.*, 10.1061/(ASCE)ME.1943-5479.0000062, 224–230.

McGraw-Hill Construction. (2012). "The business value of BIM in North America: Multi-year trend analysis and user ratings (2007–2012)." *SmartMarket Rep.*, New York.

McGraw-Hill Construction. (2014). "The business value of BIM for owners." *SmartMarket Rep.*, New York.

NIBS (National Institute of Building Sciences). (2007). *National building information modeling standard—Version 1.0—Part 1: Overview, principles and methodologies*, Washington, DC.

Nightingale, D., and Mize, J. (2002). "Development of a lean enterprise transformation maturity model." *Inf. Knowl. Syst. Manage.*, 3(1), 15–30.

NIST (National Institute of Standards and Technology). (2012). "Baldrige performance excellence program." ⟨http://www.nist.gov/baldrige/about/faqs_using_criteria.cfm⟩ (Sep. 20, 2012).

Paulk, M., Curtis, B., and Chrissis, M. B., and Weber, C. (1993). "Capability maturity model for software, version 1.1." *Technical Rep. CMU/SEI-90-TR-24*, Software Engineering Institute, Carnegie Mellon Univ., Pittsburgh.

Rowe, G., and Wright, G. (1999). "The Delphi technique as a forecasting tool: Issue and analysis." *Int. J. Forecasting*, 15(4), 353–375.

Ruikar, K., Anumba, C., and Carrillo, P. (2006). "VERDICT—An e-readiness assessment application for construction companies." *Autom. Constr.*, 15(1), 98–110.

Sarshar, R., et al. (2000). "SPICE: A business process diagnostics tool for construction projects." *Engineering Constr. Archit. Manage.*, 7(3), 241–250.

Scheibe, M., Skutch, M., and Schofer, J. (1975). "Experiments in Delphi methodology." *The Delphi method techniques and applications*, 1st Ed., Addison-Wesley, London, 262–287.

Sebastian, R., and van Berlo, L. (2010). "Tool for benchmarking BIM performance of design, engineering and construction firms in the Netherlands." *Archit. Eng. Des. Manage.*, 6(4), 254–263.

SEI (Software Engineering Institute). (2011). "Capability maturity model integration (CMMI)." ⟨http://www.sei.cmu.edu/cmmi/⟩ (Sep. 20, 2012).

Skulmoski, G., Hartman, F., and Khran, J. (2007). "The Delphi method for graduate research." *J. Inf. Technol.*, 6, 1–21.

Succar, B. (2009). "Building information modeling framework: A research and delivery foundation for industry stakeholders." *J. Autom. Constr.*, 18(3), 357–375.

Succar, B. (2010). "Building information modeling maturity matrix." *Handbook of research on building information modeling and construction informatics: Concepts and technologies*, 2nd Ed., Information Science Publishing, Hershey, PA, 65–103.

Succar, B., Sher, W., and Williams, A. (2013). "An integrated approach to BIM competency assessment, acquisition and application." *J. Autom. Constr.*, 35, 174–189.

Tulacz, G. (2012a). "2012 ENR top 400 contractors." *Engineering News-Record*, New York.

Tulacz, G. (2012b). “2012 ENR top 500 design firms.” *Engineering News-Record*, New York.

Van Berlo, L., Dikkmans, T., Hendriks, H., Spekkink, D., and Pel, W. (2012). “BIM QuickScan: Benchmark of performance in the Netherlands.” *Proc., 29th Int. Conf. on Applications of IT in the AEC Industry CIB W078*, R. Issa and C. Issa, eds., Beirut, Lebanon.

Watson, P., and Seng, L. (2001). “Implementing the European foundation for quality management model in construction.” *Construction Inf. Q.*, 130, 1–8.

Xia, B., and Chan, A. (2012). “Measuring complexity for building projects: A Delphi study.” *Engineering Constr. Archit. Manage.*, 19(1), 7–24.

J. Manage. Eng.