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BY
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BIM MATURITY ASSESSMENT AND CERTIFICATION IN CONSTRUCTION PROJECT TEAM SELECTION

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ÉVALUATION ET CERTIFICATION DE LA MATURITÉ BIM LORS DE LA SÉLECTION DE L'ÉQUIPE D'UN PROJET DE CONSTRUCTION

Ali ALAGHBANDRAD

RÉSUMÉ

Afin de mettre en œuvre, avec succès, l'approche BIM dans un projet de construction, tous les participants du projet, en tant qu'utilisateurs du BIM, doivent posséder un minimum de capacités BIM. Avant le début d'un projet, l'évaluation des capacités BIM des intervenants de projet est une préoccupation majeure pour les clients de construction. Les clients du domaine de la construction n'ont actuellement aucun mécanisme afin de s'assurer que les participants clés qu'ils veulent engager, pour un projet de construction, possèdent les capacités (c.-à-d. les qualifications) minimales afin de participer pleinement à la conception et la livraison d'un projet de construction qui utilise une approche BIM. L'importante variabilité de la maîtrise du BIM peut causer des coûts additionnels aux clients ainsi que nuire aux membres les plus matures du projet. Donc, les clients du domaine de la construction ont besoin de s'assurer d'un minimum de maturité BIM, préalablement à la sélection de leurs fournisseurs. Les différentes propositions de modèles de maturité BIM actuels tentent d'évaluer la maturité BIM des firmes, mais ne se concentrent pas sur l'utilisation BIM. Les cas d'utilisation spécifiques de BIM sont au centre des bénéfices escomptés du BIM. Ce projet de recherche propose donc un nouveau modèle de maturité BIM qui se concentre sur les capacités des firmes en utilisation spécifiques de BIM. La méthodologie de recherche est basée sur une révision détaillée de la littérature et plusieures discussions avec des groupes d'experts. À L'aide de la revue de littérature, les chercheurs ont concu un premier modèle de maturité. Par la suite, des experts BIM ont discuté des améliorations possibles aux pratiques décrivant les utilisations spécifiques du BIM. Il est attendu que par l'utilisation de ce modèle, les clients de construction pourront obtenir plus d'avantages du BIM à travers la sélection de fournisseurs qualifiés.

Mots-clés : modélisation de l'information du batiment (BIM), modèle de maturité BIM, construction, certification BIM

BIM MATURITY ASSESSMENT AND CERTIFICATION IN CONSTRUCTION PROJECT TEAM SELECTION

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ABSTRACT

To implement BIM in a construction project successfully, all the project participants, as BIM users, must have minimum BIM capabilities. Before any project starts, assessing the BIM capabilities of project stakeholders is a concern for construction clients. The main problem however is that they have no mechanism to ensure that the key participants they hire for a BIM project have the minimum capabilities (BIM infrastructure, processes and qualified resources) to participate in the design and delivery of a BIM project. The high variability of a firms' readiness to work with BIM may impose a high cost for the client and the most mature members of the supply chain. Therefore, construction clients need a way to ensure a minimum BIM maturity, such as a maturity audit to assess the BIM competency of potential project team members. From a client's perspective, "minimum BIM qualification" means "minimum capability to use BIM". The current BIM maturity models try to assess the BIM capability level of firms, but do not focus on BIM Uses. This research proposes a maturity model that focuses on the capability of firms for specific BIM Uses, while measuring their general BIM competencies. The research methodology is based on a review of literature and focus group discussions. Through literature review, the researchers proposed a BIM uses maturity model. Then, BIM experts discussed possible improvements. After an analysis of the discussion, the author proposed the resulting model. It is expected that by using this model, construction clients may achieve more BIM benefits through the selection of BIM qualified project team members, i.e. reduced cost, time, and increased quality of project.

Keywords: building information modeling (BIM), BIM maturity model, construction, BIM certification

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LIST OF ABBREVIATIONS

3D	3 Dimensions
4D	4 Dimensions
AEC	Architectural, Engineering, Construction
AIA	American Institute of Architects
BIM	Building Information Modeling
BIMUMM	Building Information Modeling Uses Maturity Model
CAD	Computer Aided Design
CIC	Computer Integrated Construction
CMM	Capability Maturity Model
CMMI	Capability Maturity Model Integration
COBie	Construction-Operations Building information exchange
CPU	Central Processing Unit
DDC	Department of Design and Construction
FM	Facility Management
QMMG	Quality Management Maturity Grid
ICT	Information and Communication Technology
IFC	Industry Foundation Class
IPD	Integrated Project Delivery
ISO	International Organization for Standardization
IU	Indiana University
KPA	Key Process Area
KPI	Key Performance Indicator

LOD	Level Of Detail/Level Of Development
MEB	Model Element Breakdown
MEP	Mechanical, Electrical, and Plumbing
O&M	Operation and Maintenance
PC	Personal Computer
PLM	Product Lifecycle Management
NBIMS	National Building Information Model Standard
NIBS	National Institute of Building Sciences
RFQ	Request For Qualification
RFP	Request For Proposal
RFI	Request For Information
ROI	Return On Investment
SEI	Software Engineering Institute

INTRODUCTION

The construction industry has been facing many problems and barriers in the past two decades, such as cost overruns, time delays, prolonged contractual claims (Liberda et al., 2003), disputes (Musonda, 2011), and labor productivity decline (Teicholz, 2004), leading to low performance and productivity. In addition, characteristics of construction industry, such as the project-oriented nature and the uniqueness of every project (Wegelius-Lehtonen, 2001), multi-disciplinary, cross-organizational, the organizational change of Architectural, Engineering, and Construction (AEC) project teams (Liston, 2009), and fragmented supply chains (Cox and Ireland, 2002), increases the complexity of working on large construction initiatives. To improve productivity of the construction industry, different solutions such as digital construction are emphasized. Digital construction aims to address the growing fragmentation problems and improve productivity by using technologies such as BIM for integrating processes throughout the entire lifecycle of a construction project. BIM proposes a consistent digital information platform to be used by the stakeholders throughout the lifecycle of the project. To date, many construction projects have reported benefits from the use of BIM technology and BIM is recommended as a remedy for productivity issues (Mihindu and Arayici, 2008). According to McGraw-Hill (2009) the most notable reported BIM benefits to a project, include: reduced conflicts during construction, improved collective understanding of design intent, improved overall project quality, reduced changes during construction, reduced number of RFIs (Requests for Information), and better cost control/predictability.

To implement BIM in a project successfully and fully benefit from its use, all the project members, as users of BIM, should demonstrate minimum BIM capabilities. However, clients have no mechanism to measure the minimum BIM capabilities (BIM infrastructure, processes and qualified resources) of the key suppliers to participate in the design and delivery of the project using BIM technology. The high variability of BIM maturity levels of project members may result in high costs for the client and the most mature members of the supply chain. Therefore, a way to help solve this issue is that project members obtain and provide a BIM maturity certificate, granted by an independent party, in order to participate in project team selection process.

The research motivation is the lack of a BIM maturity assessment model to evaluate firms in achieving specific BIM Uses, as unique tasks or procedures “on a project which can benefit from the integration of BIM into that process” (CIC, 2011, p. 1). The **research question** is:

- How can the current BIM maturity models evolve to develop a BIM maturity model for construction project clients to pre-qualify project applicant firms in BIM?

To answer the research question, the **research objective** is defined as follows:

- This research aims to develop a prototype of a BIM use maturity model, which could be used to assess the BIM maturity of construction project applicants, so that the client can verify if the applicant firms of project are pre-qualified in BIM. The assessment process occurs before the project bid and is performed by an independent party.

This thesis includes seven chapters. In chapter 1, the current practice of the construction industry is investigated and BIM is introduced as a solution. Then BIM is defined, different uses of BIM in projects are introduced, and BIM impacts and benefits are explained. In chapter 2, the concept of a maturity model is explained, a brief history of maturity models is provided, BIM maturity model is introduced, different BIM maturity models are reviewed and their contribution to this research in analyzed. In chapter 3, the BIM Uses Maturity Model (BIMUMM) is proposed. The recommended perspective, architecture, maturity scale, and evaluation process of this model is described in this chapter. Chapter 4 explains the research methodology, the research question and objectives are described, the method of model development is discussed, and the model validation is presented. Chapter 5 presents the BIM domain of ‘Processes’. In this domain, BIM maturity practices are presented within four Key Process Areas (KPAs) of ‘Design Authoring’, ‘3D Coordination’, ‘Design Review’, and ‘BIM Project Management’. Chapter 6 includes detailed practices of the BIM resources domain, within the two KPAs of ‘Infrastructure’ and ‘Human Resources’. The proposed BIMUMM validation method and results are explained in chapter 7.

The result of this research contributes to the BIM maturity assessment area for the purpose of project team selection. Maturity assessment of BIM Uses in the proposed model fill the gap of previous BIM maturity models in considering BIM Uses maturity measurement, and establish a new basis for future development in this area. Integration of BIM maturity practices from different resources in the proposed model is another contibution of this research.

CHAPTER 1

BUILDING INFORMATION MODELING (BIM)

In this chapter, the current practice in the construction industry is presented and BIM is introduced as a solution. BIM definition and uses in a construction project, its impact and its benefits is also presented in this chapter.

1.1 Current Practice in the Construction Industry

Labor productivity has declined in the construction industry over last forty years (Teicholz, 2004). Various causes lead to this productivity decline. Uniqueness of projects in the construction industry (Wegelius-Lehtonen, 2001; Teicholz, 2004) make it difficult to take advantages of past « lessons learned » for future projects and to optimize knowledge (Teicholz, 2004). The construction industry is multi-disciplinary, and cross-organizational (Liston, 2009) with a fragmented supply chain (Cox and Ireland, 2002). A lack of integration of design and construction and poor collaboration between team members (Teicholz, 2004) lead to cost overruns, time delays, and contractual claims (Teicholz, 2004; Liberda et al., 2003).

To increase productivity, by overcoming the existing problems in the construction industry and its complex nature, various solutions are proposed. BIM is one of these solutions that brings values to the construction industry and can be a source of potential positive change (Teicholz, 2004).

1.2 Definition of BIM

Two perspectives exist to define BIM. One view looks at BIM as a tool for representation of building data. Another perspective considers BIM as a process to develop the model of building (see Figure 1.1).

There are different characteristics attributed to BIM as a tool. In this way, BIM is defined as "a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward" (NIBS, 2007). According to Eastman et al. (2011), « with BIM technology, one or more accurate virtual models of a building are constructed digitally. They support design through its phases, allowing better analysis and control than manual processes. When completed, these computer-generated models contain precise geometry and data needed to support the construction, fabrication, and procurement activities through which the building is realized » (p. 1).

Different definitions are presented to describe the Building Information Modeling (BIM) process. For this purpose, BIM is defined as "… a process focused on the development, use and transfer of a digital information model of a building project to improve the design, construction and operations of a project or portfolio of facilities" (CIC, 2011, p. 1) or "…The process of creating and using digital models for design, construction and/or operations of projects" (McGraw-Hill Construction, 2009, p. 4). This process includes "a set of interacting policies, processes and technologies (Succar, 2009) generating a 'methodology to manage the essential building design and project data in digital format throughout the building's life-cycle'" (Penttila, 2006)" (as cited in Succar, 2010a, p. 66).

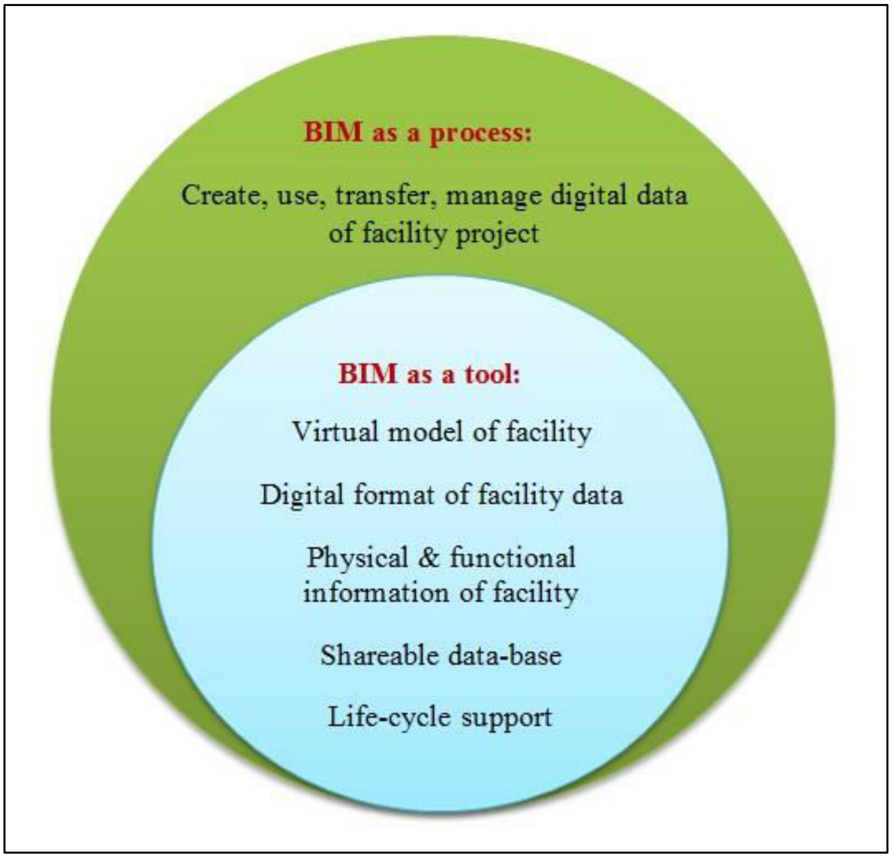


Figure 1.1 BIM as a process and a tool
Adapted from NIBS, (2007); McGraw-Hill, (2009); Succar, (2010a), CIC, (2011); Eastman et al., (2011); Staub-French et al., (2011)

BIM tools enable parametric object-based modeling of a building (refer to Figure 1.2). In BIM, modeling building components are more than just creating their geometric information by line, surface, and volume. More properties can be added to the components. In BIM applications, sets of object classes and families are pre-defined. Modeling is automated in BIM. It means that the object automatically updates when a change happens in the model and affects other object (Eastman et al., 2011). Figure 1.2 demonstrates an exterior curtain wall, which is defined in a parametric table of Autodesk Architecture Revit 2014.

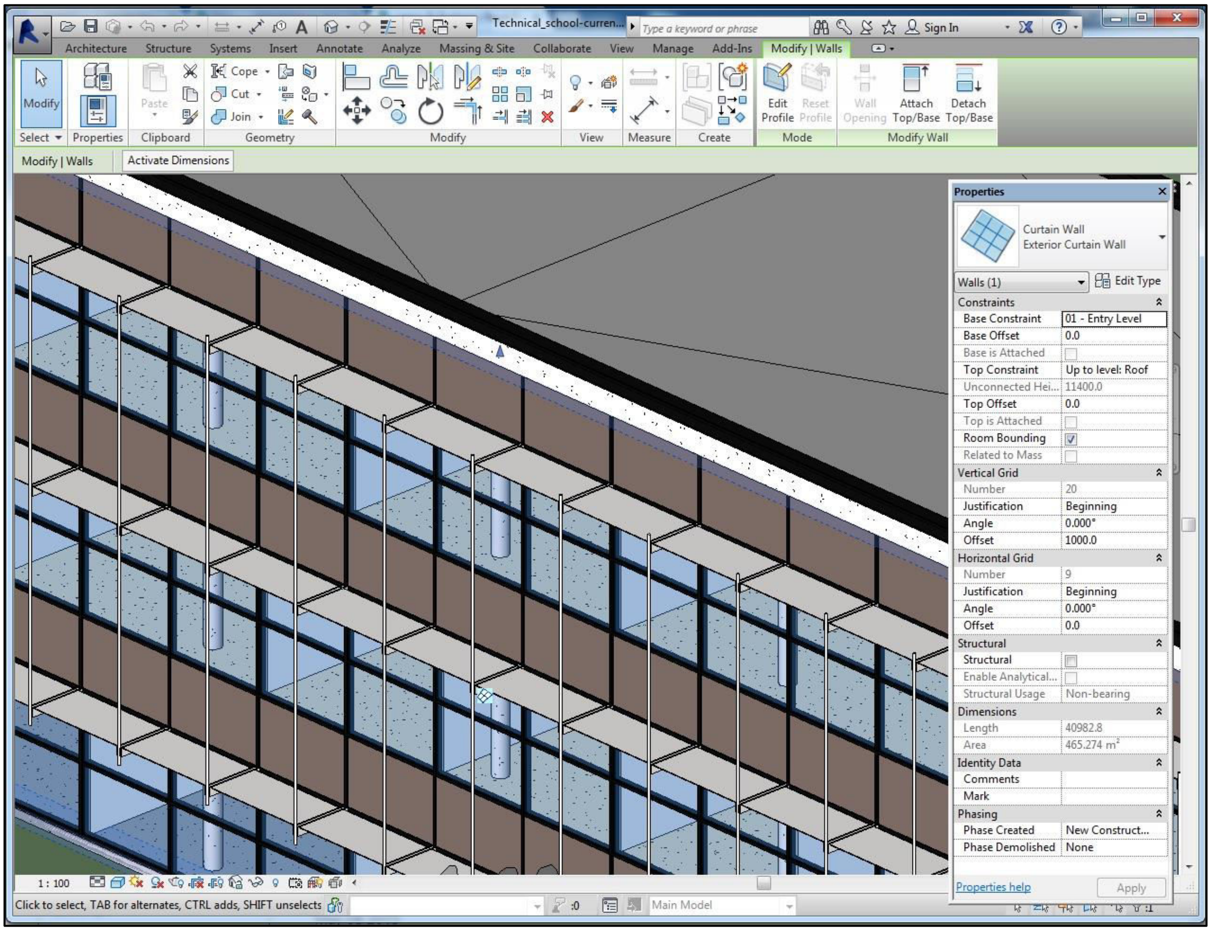


Figure 1.2 An example of parametric modeling-Exterior curtain wall
Taken from software of Revit Architecture (2014)

1.3 BIM Uses

According to CIC (2011), « A BIM Use is a unique task or procedure on a project which can benefit from the integration of BIM into that process » (p. 1). BIM can be used during all phases of the project for various tasks by different project members, such as architects, engineers, contractors, and owners. CIC (2011) identified 25 BIM Uses, within different phases of a project, namely, Planning, Design, Construction, and Operation, as shown in Figure 1.3. Some BIM Uses can be performed in more than one project phase. For example, BIM can be used for cost estimation during the whole lifecycle of a project. Design reviews can be performed in both 'planning' and 'design' phases of project.

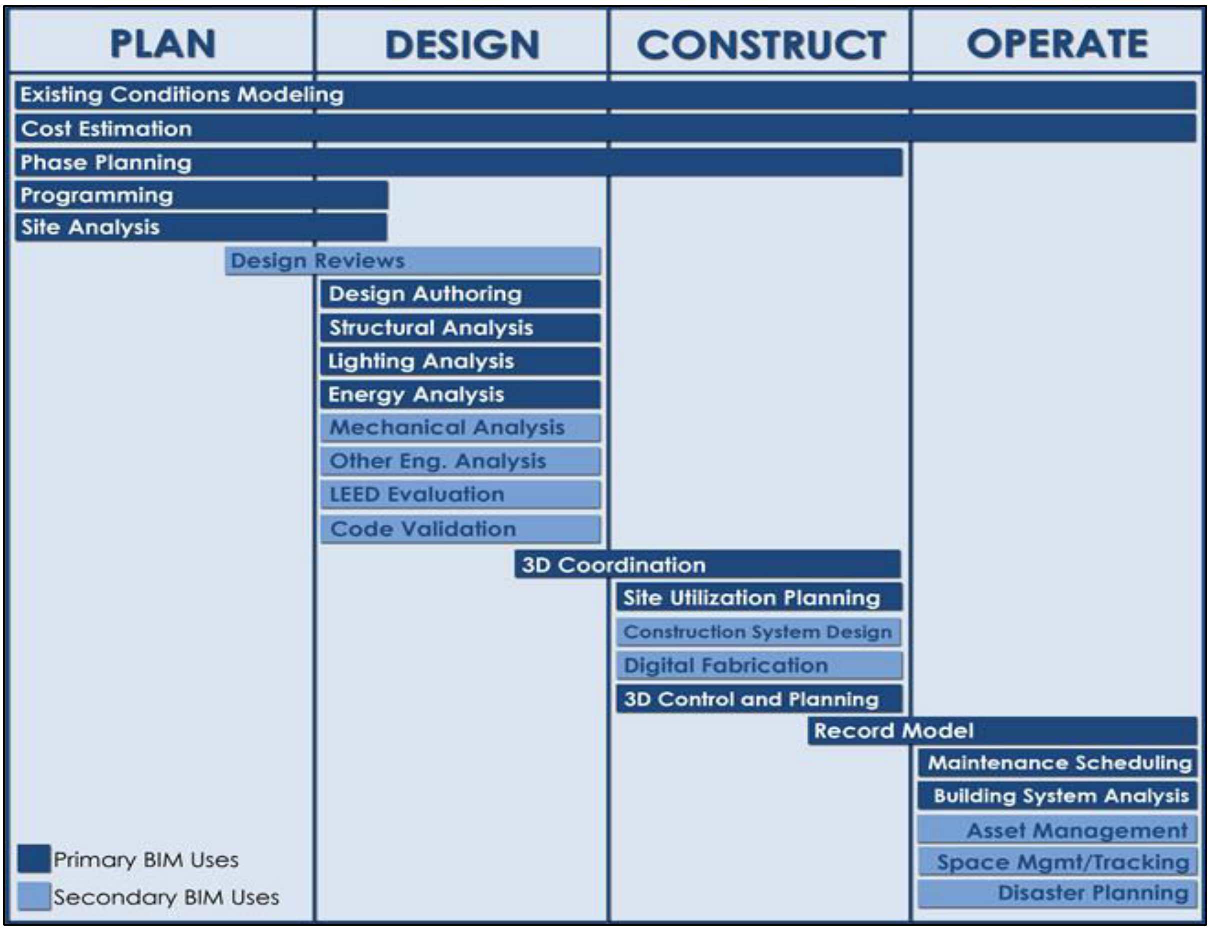


Figure 1.3 BIM Uses throughout a building lifecycle
Taken from CIC (2011)

McGraw-Hill Construction (2012) also identified different BIM Uses or BIM activities, as shown in Figure 1.4. Primary BIM uses are considered as the uses with more frequency of use on project, in compare of secondary BIM uses. However, 'Design Reviews' must be considered as a primary BIM use, since it is ranked as second most frequent BIM use in the survey of Kreider et al. (2010). BIM activities are categorized within two project phases of 'design' and 'construction'.

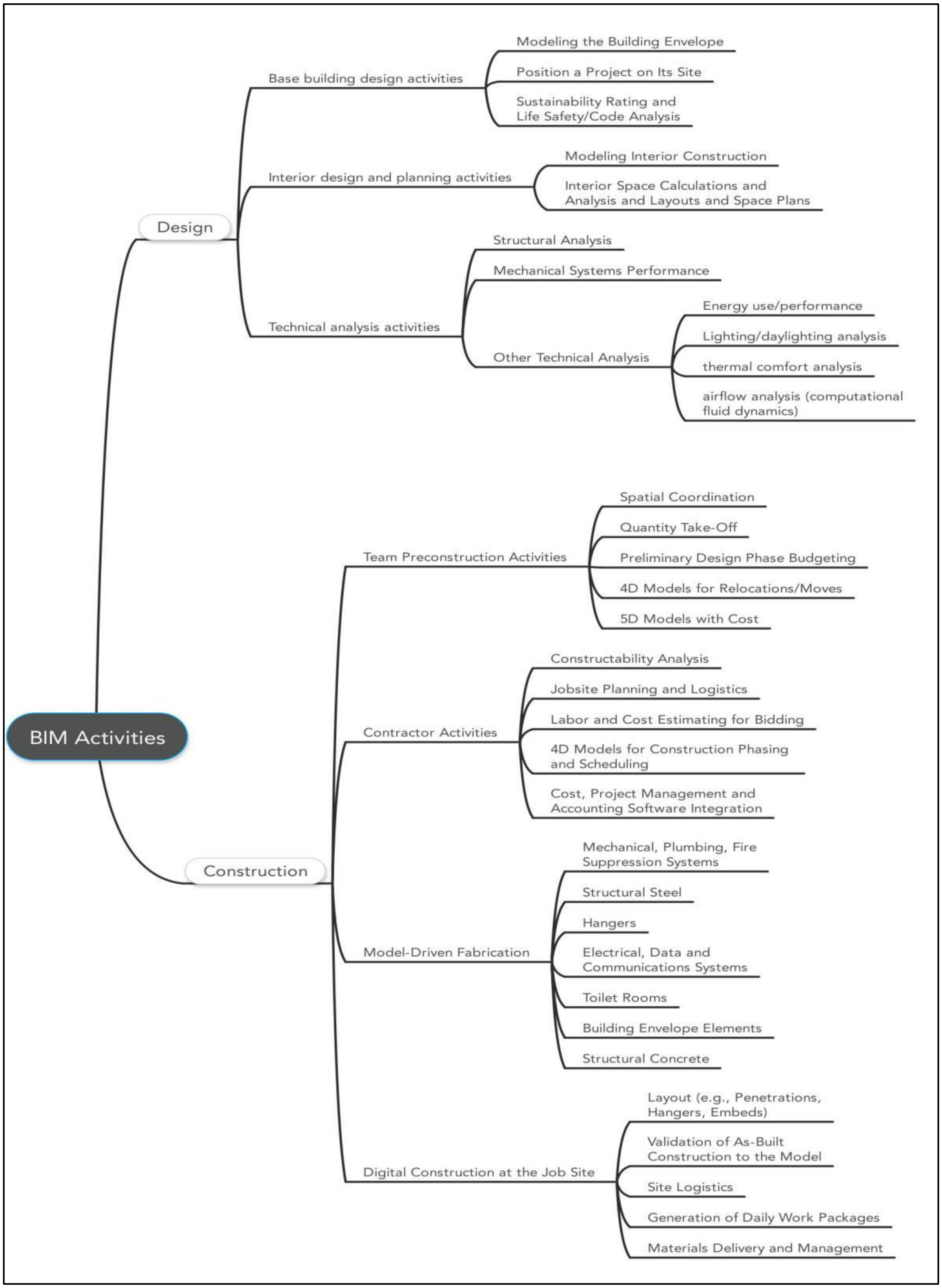


Figure 1.4 BIM activities
Adapted from McGraw-Hill Construction, (2012)

By reviewing the two above references (McGraw-Hill Construction, 2012; CIC, 2011), it can be understood that BIM can be used in different phases of the project, by different project players. However, depending on each specific BIM use, a level of collaboration among project members for using BIM may be required. For example, as shown in Figure 1.3, '3D coordination' is a BIM use in the design and construction phases. Therefore, the collaboration of the design and the construction teams may be an important factor in the success of '3D coordination' BIM use. One of the critical issues in collaboration of project participants for BIM may be their different BIM maturity levels, which means that low level maturity misuses BIM content. To reduce the collaboration problems in using BIM, a minimum BIM capability maturity level may be required for each project participant.

1.4 BIM impacts and Benefits

Different researchers mentioned the achieved benefits through the use of BIM. According to McGraw-Hill's "SmartMarket Report on Building Information Modeling: Transforming Design and Construction to Achieve Greater Industry Productivity" (2008), the surveyed companies, who are actively tracking BIM return on investment (ROI), get 300% to 500% initial BIM ROIs on projects using BIM.

McGraw-Hill Construction (2009) identified the BIM benefits that bring most value to a project as follows: "Reduced conflicts during construction, improved collective understanding of design intent, improved overall project quality, reduced changes during construction, reduced number of RFIs (Requests for Information)" and finally "Better cost control/predictability" (p. 22).

The potential benefits of BIM adoption in many projects are (TOCOMAN, 2008; Takes, 2008; as cited in Mihindu & Arayici, 2008) "… 1) faster and more effective processes, 2) better design, 3) controlled whole life and environmental data, 4) better production quality, 5) automated assembly, 6) better customer service, 7) lifecycle data, 8) integration of planning and implementation processes, 9) more effective and competitive industry".

Although in literature review, many benefits are observed from using BIM, it is difficult to quantify these benefits. Barlish and Sullivan (2012) found that the most quantifiable benefits are: schedule, change orders, request for information (RFIs), and project or pilot cost. However, there are other benefits, which are not easily quantifiable. For example, it is not easy to quantify quality improvement of a project by using BIM since measuring ‘quality’ can vary from case to case.

Another issue in achieving these benefits is the effect of different factors in the degree to which a BIM value can be reached. For example, the BIM competency or maturity level of firms in using BIM can affect the reached level of BIM benefits.

In the next chapter, the concept of BIM maturity is introduced and several BIM maturity models are reviewed.

CHAPTER 2

BIM CAPABILITY ASSESSMENT

2.1 Concept of a Maturity Model

A “maturity model” can be defined as “… a conceptual framework, with constituent parts, that defines maturity in the area of interest. […] In some cases, […], a maturity model may also describe a process whereby an organization can develop or achieve something desirable, such as a set of Capabilities or practices” (OPM3, 2003, p. 5).

Capability Maturity Models (CMMs) are originally from the field of quality management (Crosby, 1979) and identify a set of standardized process improvement levels to enable implementers in obtaining significant business benefits (Succar, 2010a). The goal of the Quality Management Maturity Grid (QMMG) developed by Crosby (1979) was to enable organizations to understand how mature they are in quality management and was “… valuable in comparing the status of different companies or divisions. It also provides a continual source of direction concerning what needs to be done next” (Crosby, 1979, p. 40). This 5×6 maturity grid (Figure 2.1) presents five evolutionary stages of an organization’s maturity in quality management against six quality management categories.

QUALITY MANAGEMENT MATURITY GRID Rater: Unit:					
Measurement Categories	**Stage 1: Uncertainty**	**Stage 2: Awakening**	**Stage 3: Enlightenment**	**Stage 4: Wisdom**	**Stage 5: Certainty**
Management understanding and attitude	No comprehension of quality as a management tool. Tend to blame quality department for "quality problems."	Recognizing that quality management may be of value but not willing to provide money or time to make it all happen.	While going through quality improvement program learn more about quality management; becoming supportive and helpful.	Participating. Understand absolutes of quality management. Recognize their personal role in continuing emphasis.	Consider quality management an essential part of company system.
Quality organization status	Quality is hidden in manufacturing or engineering departments. Inspection probably not part of organization. Emphasis on appraisal and sorting.	A stronger quality leader is appointed but main emphasis is still on appraisal and moving the product.	Quality department reports to top management, all appraisal is incorporated and manager has role in management of company.	Quality manager is an officer of company; effective status reporting and preventing action. Involved with consumer affairs and special assignments.	Quality manager on board of directors. Prevention is main concern. Quality is a thought leader.
Problem handling	Problems are fought as they occur; no resolution; inadequate definition; lots of yelling and accusations	Teams are set up to attack major problems. Long-range solutions are not solicited.	Corrective action communication established. Problems are faced openly and resolved in an orderly way.	Problems are identified early in their development. All functions are open to suggestion and improvement.	Except in the most unusual cases, problems are prevented.
Cost of quality as % of sales	Reported: unknown Actual: 20%	Reported: 3% Actual: 18%	Reported: 8% Actual: 12%	Reported: 6.5% Actual: 8%	Reported: 2.5% Actual: 20%
Quality improvement actions	No organized activities. No understanding of such activities.	Trying obvious "motivational" short-range efforts.	Implementation of the 14-step program with thorough understanding and establishment of each step.	Continuing the 14-step program and starting Make Certain.	Quality improvement is a normal and continued activity.
Summation of company quality posture	"We don't know why we have problems with quality."	"Is it absolutely necessary to always have problems with quality?"	"Through management commitment and quality improvement we are identifying and resolving our problems."	"Defect prevention is a routine part of our operation."	"We know why we do not have problems with quality."

Figure 2.1 Quality Management Maturity Grid
Taken from Crosby (1979)

For an evaluation using Crosby's (1979) maturity grid, a number of people are asked to rate the company based on their subjective judgment about the stage of the company in each of the six measurement categories. A value of 1 to 5 is awarded to each stage respectively from "Uncertainty" to "Certainty". The total score of organization's maturity in quality management is calculated by adding all awarded values, which would be a maximum sum of 30 (Crosby, 1979).

The maturity framework of Crosby (1979) was adapted to the Software Engineering industry (Paulk et al., 1993). The Software Engineering Institute (SEI) defined Capability Maturity Models (CMMs), which "… focus on improving processes in an organization. They contain the essential elements of effective processes for one or more disciplines and describe an evolutionary improvement path from ad hoc, immature processes to disciplined, mature processes with improved quality and effectiveness. […] The essential elements of effective processes […] are based on the concepts developed by Crosby, Deming, Juran, and Humphrey" (SEI, 2010b, p. 4). The CMM worked originally "… as a tool to evaluate the ability of government contractors to perform a software project. […] Its successor, the more comprehensive Capability Maturity Model Integration (CMMI), continues to be developed and extended by the Software Engineering Institute, Carnegie Mellon University" (Succar, 2010a, p. 77).

The concept of maturity has also been applied to BIM in the construction industry, because BIM is also defined as a process (see section 1.2), which can include a set of improvement levels.

Bew-Richards' BIM maturity map (Department of Business, Innovation and Skills (2011) as cited in Barlish and Sullivan, 2012), as shown in Figure 2.2, represents different levels of BIM maturity from level 0 to 3, where Computer Aided Design (CAD) is defined at level 0 (no BIM maturity), and life-cycle management with BIM is defined at the highest level of maturity. Creating 2D and 3D models and BIM collaboration start at level 1 and 2. At level 3, interoperable data exchange and integrated web services exist. Levels 1 to 3 are supported by different standards regarding BIM, which clarify more detail about quality of BIM in each level.

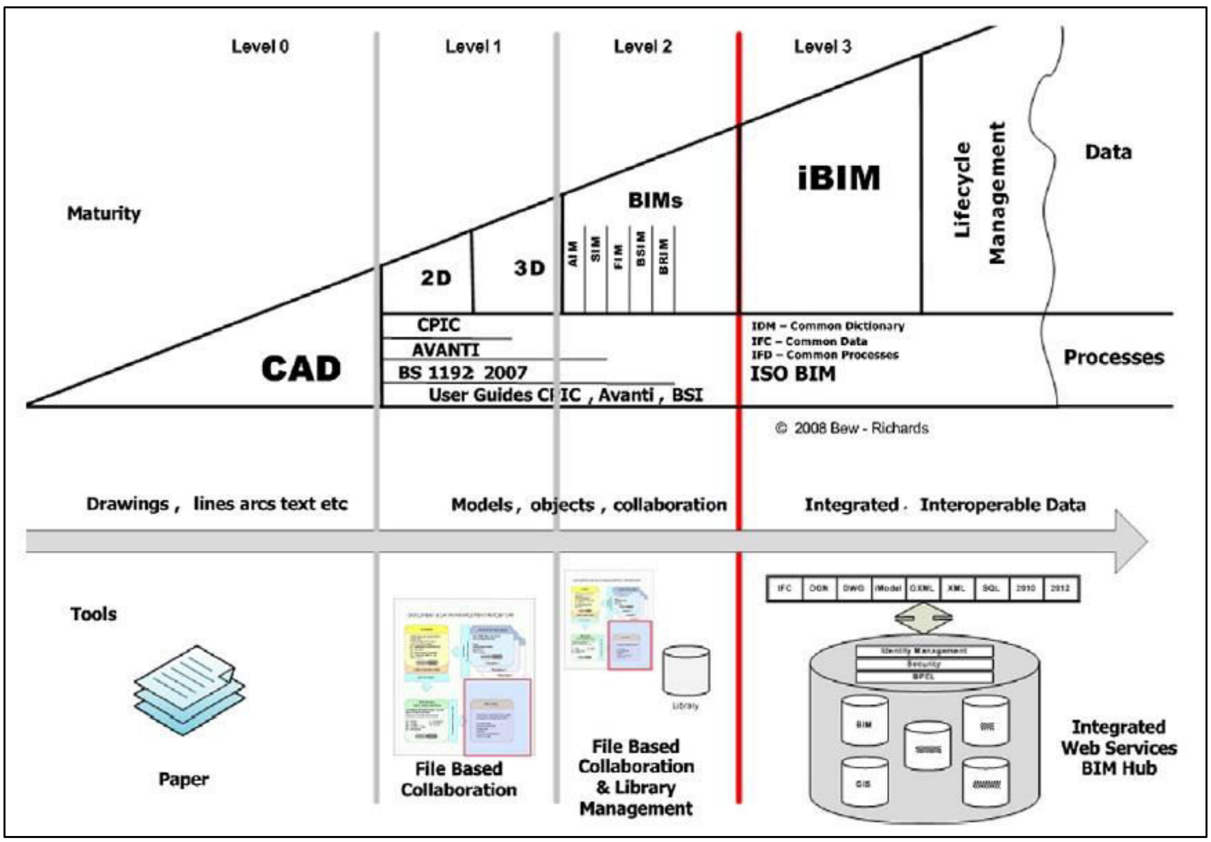


Figure 2.2 Bew-Richards BIM maturity map
Taken from Department of Business, Innovation and Skills (2011) as cited in Barlish and Sullivan, (2012)

Numerous BIM maturity models are developed for different purposes. These purposes can be explained as follows:

1) BIM Maturity Assessment for Project Team Selection:

BIM maturity assessment tools can be used in order to evaluate BIM competency of firms for a project team selection. The results of McGraw-Hill Construction (2012) research on North America revealed the importance of BIM capability for project team selection, as shown in Figure 2.3. 80% (28% + 52%) of the respondents (BIM users) consider importance of BIM capability for their project team selection.

Importance of BIM Capability for Project Team Selection

Source: McGraw-Hill Construction, 2012

Importance of BIM Capability for Project Team Selection	All BIM Users
We Require Companies be Experienced in BIM.	28%
We Encourage BIM Expertise, But Do Not Require It.	52%
BIM Expertise Does Not Affect Our Decisions.	19%

Figure 2.3 Importance of BIM capability for project team selection
Taken from McGraw-Hill Construction, (2012)

2) BIM Maturity Assessment for Minimum BIM Certification:

The National Building Information Model Standard (NBIMS) (2007; 2012) introduced the concept of using the Capability Maturity Model to define a minimum BIM capability, and looked at what this constitutes. This minimum level is defined as having some characteristics in the associated areas of maturity, and by achieving a certain score in an evaluation.

3) BIM Maturity Assessment for Performance Measurement and Improvement:

Although a BIM maturity assessment tool can work as a measurement tool to evaluate the BIM capability maturity level of firms, its use can also lead to BIM maturity improvements.

By knowing the current maturity level, a firm can plan to achieve a target level of BIM maturity (i.e. Organizational Assessment Profile (CIC, 2012)).

This research investigates several BIM maturity models, which have been developed for different purposes (i.e. Succar, 2010a,b; Succar et al., 2012; Sebastian and Van Berlo, 2010; CIC, 2011, 2012; Indiana University, 2012; NIBS, 2007, 2012). Table 2.1 presents the purpose of each model.

Table 2.1 Purposes of BIM Maturity Models

Purposes	**Project team selection**	**Minimum BIM certification**	**Performance measurement and improvement**
Models	BIM Quick Scan (Sebastian & Van Berlo, 2010)	NBIMS Capability Maturity Model (NIBS, 2007; 2012)	BIM Maturity Matrix (BIm³) (Succar, 2010a,b; Succar et al., 2012)
	BIM Qualifications Scoring Matrix (CIC, 2012)		Organizational BIM Assessment Profile (CIC, 2012)
	BIM Proposal Scoring Matrix (CIC, 2012)		
	IU BIM Proficiency Matrix (Indiana University, 2012)		

Each one of these BIM maturity models has its own BIM categories that are used to assess maturity. Figure 2.4 provides a representation of BIM categories, defined in four BIM areas of a) management; b) human resources; c) technological infrastructure; and d) BIM information. As cited in in Figure 2.4 for these four BIM areas, BIM area of “Management” considers BIM-related management capabilities of firms/project members. The area of “Human Resources” is about the human resources dedicated for BIM, BIM competency of personnel, their roles, and educational programs of firms. The area of "Technological Infrastructure" considers supporting software, hardware, and network for BIM, and the way of using and updating them. The area of "BIM Information" is about different subjects, such as BIM information flow, BIM model contents and modeling, use of BIM, etc.

BIM Area	IU BIM proficiency matrix (Indiana University, 2012)	BIM Proposal Scoring Matrix (CIC, 2012)	BIM Qualifications Scoring Matrix (CIC, 2012)
Management	IPD Methodology: Creation of A BIM Execution Plan, Introduction of Structural and MEP Model, Model Managers Role Defined, IPD Methodology Innovation	Price: What is the total price for the listed services -Collaboration Procedure: What collaboration procedure is included in the proposal	BIM Project Execution Planning Experience: Experience the team has with planning for BIM on projects. -Collaboration Experience: Willingness of the team to collaborate with others and their experience collaborating.
Human resources	IPD Methodology:Model Managers Role Defined	Project Team Qualification: How much experience and success has the proposed project team had	BIM Tools: Competence of the project team in implementing various BIM tools. -Technical Capabilities: Abilities of the organization to preform BIM
Technological infrastructure	Not available	Not available	Not available
BIM information	Physical Accuracy of Model: Basic Model Geometry, Design Requirements, Design Side Collision Detection, Model Accuracy Innovation -Calculation Mentality: Basic Model Information Export (Discipline), IPD Integration, Interdisciplinary Calculations, Calculations Innovation -Location Awareness: Site Orientation, Existing Environment Awareness, Global Accuracy, Location Innovation -Content Creation: Geometrically Correct Content, Manufacturer's Specific, Design Intent, Content Innovation -Construction Data: Quantity Takeoffs, Object Scheduling, Material Procurement, Construction Innovation -As-Built Modeling: Post Bid Model Documentation, Coordination Modeling, Recapturing Design Intent, As-Built Innovation -FM Data Richness: Space Management Data, Asset Management, Manufacturer Specific Information, FM Data	Additional BIM Uses: What additional BIM services are proposed -Deliverables: What are the deliverables proposed	Not available

Figure 2.4 Comparison of BIM Maturity Models

BIM Area	BIM Quick Scan tool (Sebastian and Van Berlo, 2010)	Organizational BIM Assessment Profile (CIC, 2012)	BIM maturity matrix (Succar et al., 2012)	Capability maturity model (NBIMS, 2007, 2012)
Management	Organization and management: Vision and strategy, distribution of roles and tasks, organization structure, quality assurance, financial resources and partnership on corporate and project level	Strategy: Organizational Mission and Goals, BIM Vision and Objectives, Management Support, BIM Champion, BIM Planning Committee	Policy: Benchmarks & Controls, Contracts & Agreements, Guidance & Supervision -Process: Leadership & Management, Activities & Workflows	Life-cycle Views -Change Management -Business Process
Human resources	Mentality and culture: BIM acceptance among the staff and workers, group and individual motivation, presence and influence of the BIM coordinator, knowledge and skills, knowledge management and training	Personnel: Roles and Responsibilities, Organizational Hierarchy, Education, Training, Change Readiness	Process: Resources	Roles or Disciplines
Technological infrastructure	Tools and applications: Use of model server, type and capacity of model server, type of software package, advanced BIM tools, model view definitions and supporting rules	Infrastructure: Software, Hardware, Physical Spaces	Technology: Software, Hardware, Data & Networks	Interoperability/ IFC Support
BIM information	Information structure and information flow: Use of modeling, open ICT standards, object libraries, internal and external information flow, type of data	Information: Model Element Breakdown (MEB), Level of Development (LOD), Facility Data -BIM Uses: Project Uses, Operational Uses -Process: Project Processes, Organizational Processes	Process: Products & Services	Data Richness -Timeliness/ Response -Delivery Method -Graphical Information -Spatial Capability -Information Accuracy

Figure 2.4 (continued) Comparison of BIM Maturity Models

A review of the above BIM maturity models reveals that BIM fields can be categorized in different ways, with more or less details. There is no standard way to categorize BIM subjects in a BIM maturity model. It depends on the purpose and expectations of model developers and users for the application of a model.

2.2 BIM Maturity Assessment for Project Team Selection

As Table 2.1 indicates, four BIM maturity models were developed for the purpose of project team selection. This section reviews these models.

2.2.1 BIM Quick Scan tool

Sebastian and Van Berlo (2010) developed the BIM Quick Scan tool to benchmark the current BIM performance level of AEC organizations for the Dutch construction industry. The purpose was to justify qualification of project parties to be involved in projects and to "… raise awareness and establish a common strategy for innovation through BIM" (Sebastian & Van Berlo, 2010, p. 254). In this approach, a certified BIM consultant carries out the assessment upon request of an organization and produces an assessment report. This approach combines quantitative and qualitative assessments of the 'hard' and 'soft' aspects of BIM at the a) corporate level, b) ICT infrastructure level, and c) model/modeling level. Four main chapters of an organization, including: 1) organization and management; 2) mentality and culture; 3) information structure and information flow; and 4) tools and applications, are assessed by the BIM Quick Scan tool. Each one of these chapters contains a number of Key Performance Indicators (KPIs) "… in the form of a multiple-choice questionnaire. […] With each KPI, there are a number of possible answers. For each answer, a score is assigned. Each KPI also carries a certain weighting factor. The sum of all the partial scores after considering the weighting factors represents the total score of BIM performance of an organization" (Sebastian & Van Berlo, 2010, pp. 258 and 259). KPIs are assessed using a percentile scale and then the chapters are assessed with a five-level scale of 0 to 4 (Sebastian & Van Berlo, 2010). The tool asks about the presence of 'BIM Uses' in the firm, but there is a problem associated with the categorization of BIM Uses. While some of these BIM Uses are specific, such as planning (4D) and quantities/costing, the others are very general, such as simulations, design, architectural, construction, etc. In addition, although it asks for the presence of a BIM Use, the maturity level of a specific BIM Use is not evaluated by the tool. For example, if a firm has BIM 4D planning, this assessment tool cannot assess how well the firm is using BIM for planning (4D) with a scale.

2.2.2 BIM Qualifications and Proposal Scoring Matrix

According to CIC (2012), the BIM maturity level of project applicants must be evaluated during the team selection stage, namely during Request For Qualification (RFQ) and Request For Proposal (RFP). At the project team selection stage, to enable the owner to measure the BIM maturity level of applicants, two BIM capability maturity models are presented. The owner asks about BIM experience and the expertise of applicants in the RFQ. In analyzing the submitted RFQs, a matrix similar to the 'BIM Qualifications Scoring Matrix', shown in Figure 2.5, "assists the owner in organizing the submissions into a quantifiable score that can quickly and easily be ranked" (CIC, 2012, p. 57). To enable an owner to filter possible exaggerated BIM qualifications, applicants must provide proof of the qualifications they claim to have, for example, by answering questions of owner as presented in Appendix V.

Category	Description	Level of Maturity						Score	Possible
		0	1	2	3	4	5		
BIM Project Execution Planning Experience	Experience the team has with planning for BIM on projects	Team has no experience with BIM planning on a project	Team has completed discrete BIM Uses but has not composed a BIM plan	Team has assisted in BIM Planning with other teams	Team has led BIM planning on projects	Team has integrated BIM planning into standard operating procedures	Team has developed a standard BIM Execution Plan to use on projects	1	5
Collaboration Experience	Willingness of the team to collaborate with others and their experience collaborating	Team has not collaborated with other teams and does not encourage collaboration	Team has collaborated on previous projects, but is not willing to share model/information fluidly	Team has experience and is willing to share information with other team members	Team leads collaboration efforts and encourages information sharing among parties	Team is willing to co-locate for a project	Team encourages co-location on all projects	2	5
BIM Tools	Competence of the project team in implimenting various BIM tools	Team has not implimented BIM and is not willing to do so	Team has not implimented BIM, but is willing to	Team has implimented BIM to a limited extent	Team has implimented BIM on many projects if required by the owner	Team impliments BIM tools on all projects	Team encourages all parties to impliment BIM tools on all project	2	5
Technical Capabilities	Ablities of the organization to preform BIM	Team does not impliment BIM or any other electronic technology	Team does not impliment BIM but utilizes limited electronic communication tools	Team does not impliment BIM but extensively uses electronic communication tools	Team Uses BIM to a limited extent and electronic communication tools	Team impliments cutting edge technologies on projects	Team is innovative in developing new technologies and BIM uses	1	5
TOTAL								6	20

Figure 2.5 BIM Qualifications Scoring Matrix
Taken from CIC, (2012)

In the RFP, the applicants must propose the BIM services that they can provide for the project, with a price. The owner can use a matrix similar to the 'BIM Proposal Scoring

Matrix', shown in Figure 2.6, in order to "rank the proposals based on the BIM services of greatest importance, and identify deficiencies in proposals prior to any contract award" (CIC, 2012).

Category	Description	Level of Maturity						Score	Possible
		0	1	2	3	4	5		
Price	What is the total price for the listed services	Price is significantly different from the estimated price	Price is significantly higher than estimated price	-	Price is close to estimated price	-	Price is lower than estimated price but still within acceptable range	1	5
Additional BIM Uses	What additional BIM services are proposed	Many Required BIM Uses are not included in the proposed	A few required BIM Uses are not included in the proposal	-	All required BIM Uses are included in the proposal	-	Required and additional BIM Uses (with added value described) are included	3	5
Project Team Qualification	How much experience and success has the proposed project team had	None	Team has had minimum success with BIM projects	Team has limited experience and success with BIM projects	Team has adequate experience with BIM projects	Team has significant experience with BIM projects	Team has expert experience with BIM projects	1	5
Collaboration Procedure	What collaboration procedure is included in the proposal	No collaboration procedure described	Team proposes a basic collaboration procedure	Team has developed a BIM Execution plan detailing collaboration	-	A detailed BIM Execution plan including a collaboration procedure is proposed	A detailed BIM Execution Plan including a collaboration procedure is proposed for every team member including onsite collaboration	2	5
Deliverables	What are the deliverables proposed	Minimum deliverables are not met	Some of the minimum deliverables are met	Most of the minimum deliverables are met	All of the minimum deliverables are met	All of the minimum deliverables are met and additional ones are proposed	All of the minimum deliverables are met and additional ones are proposed with a value added description	3	5
Total								10	25

Figure 2.6 BIM Proposal Scoring Matrix
Taken from CIC (2012)

Although this model (CIC, 2012) considers the proposed BIM Uses of applicants, it fails to measure the maturity level of a firm in performing specific BIM Uses, such as 3D Coordination, 4D Modeling, etc. The BIM assessment categories of 'BIM tools', 'Technical Capabilities', and 'Deliverables', are general in the BIM maturity assessment.

2.2.3 IU BIM Proficiency Matrix

Another BIM maturity model, in form of a matrix, was developed by Indiana University (IU) to evaluate the BIM expertise and experience of construction project participants (consultants) (Indiana University, 2012). An "IU BIM Proficiency Matrix" must be submitted to Indiana University by the design team before the contract award for construction projects of $5M or greater and the construction projects that have already used BIM. For other projects, it is encouraged but not required to submit it. The consultant scores the matrix based on the examples of previous projects, which used BIM. The IU can measure the BIM level of expertise and experience of design team by receiving the filled maturity matrix. Interested contractors can submit an “IU BIM Proficiency Matrix” to the University at the bid submittal stage (Indiana University, 2012). This matrix, which is shown in Figure 2.7, contains eight categories. Each category has four sub-categories. A total of thirty-two subcategories are scored ranging from 0 to 1. A maximum total score of thirty-two can be achieved based on this mechanism. The total achieved score locates the BIM maturity level of firm on a defined range: total score of 0 to 12 is assigned for the “Working Towards BIM” category, 13 to 18 for “Certified BIM”, 19 to 24 for “Silver”, 25 to 28 for “Gold” and 29 to 32 is assigned for “Ideal”. The problem with this scoring system is that for each subcategory a value from 0 to 1 is earned based on subjective judgement of the maturity level. This approach is not very accurate. For example, although a score of 0.45 represents a higher maturity level than a score of 0.4, it is not clear how to justify this scoring and the actual difference it represents. This model considers some BIM Uses, such as ‘Design side collision detection’ and ‘Coordination modeling’ in the maturity assessment. However, lack of development of capabilities within different maturity levels is a deficiency. According to Succar (2010a), “the matrix focuses on the accuracy and richness of the digital model (as an end-product) and has less focus on the process of creating that digital model”. In addition, the matrix has very little consideration for BIM resources. For example, the sub-category of “Model managers’ role defined” asks about the presence of a model manager for each discipline. However, the level of BIM expertise, experience, and knowledge of model managers is not considered in the scoring. The matrix also has other weaknesses, for example, in the BIM technological resources assessment. Although delivering a rich and accurate digital model is the focus of this model, the required technological infrastructure was not considered in maturity assessment.

IU BIM Proficiency Matrix

Category / Number	A - Physical Accuracy of Model	B- IPD Methodology	C - Calculation Mentality	D - Location Awareness	E - Content Creation	F - Construction Data	G - As-Built Modeling	H- FM Data Richness
1	Basic Model Geometry A.1 Point Achieved 0	Creation of A BIM Execution Plan B.1 Point Achieved 0	Basic Model Information Export (Discipline) C.1 Point Achieved 0	Site Orientation D.1 Point Achieved 0	Geometrically Correct Content E.1 Point Achieved 0	Quantity Takeoffs F.1 Point Achieved 0	Post Bid Model Documentation G.1 Point Achieved 0	Space Management Data H.1 Point Achieved 0
2	Design Requirements A.2 Point Achieved 0	Introduction of Structural and MEP Model B.2 Point Achieved 0	IPD Integration C.2 Point Achieved 0	Existing Environment Awareness D.2 Point Achieved 0	Manufacturer's Specific E.2 Point Achieved 0	Object Scheduling F.2 Point Achieved 0	Coordination Modeling G.2 Point Achieved 0	Asset Management H.2 Point Achieved 0
3	Design Side Collision Detection A.3 Point Achieved 0	Model Managers Role Defined B.3 Point Achieved 0	Interdisciplinary Calculations C.3 Point Achieved 0	Global Accuracy D.3 Point Achieved 0	Design Intent E.3 Point Achieved 0	Material Procurement F.3 Point Achieved 0	Recapturing Design Intent G.3 Point Achieved 0	Manufacturer Specific Information H.3 Point Achieved 0
4	Model Accuracy Innovation A.4 Point Achieved 0	IPD Methodology Innovation B.4 Point Achieved 0	Calculations Innovation C.4 Point Achieved 0	Location Innovation D.4 Point Achieved 0	Content Innovation E.4 Point Achieved 0	Construction Innovation F.4 Point Achieved 0	As-Built Innovation G.4 Point Achieved 0	FM Data Innovation H.4 Point Achieved 0

BIM Maturity

Category	Points Achieved	BIM Maturity Score	BIM Standard		
A - Physical Accuracy of Model	0	0	BIM Score Between 0-12	=	Working Towards BIM
B- IPD Methodology	0		BIM Score Between 13-18	=	Certified BIM
C - Calculation Mentality	0		BIM Score Between 19-24	=	Silver
D - Location Awareness	0		BIM Score Between 25-28	=	Gold
E - Content Creation	0		BIM Score Between 29-32	=	Ideal
F - Construction Data	0				
G - As-Built Modeling	0				
H- FM Data Richness	0				

Figure 2.7 Indiana University BIM Proficiency Matrix
Taken from Indiana University (2012)

It is important for construction clients to measure how well a potential project member can use a specific BIM application. All the reviewed models in section 2.2 have a common problem, which is the lack of development of capabilities in maturity levels of BIM Uses. There is a need to address this issue. It is suggested that clients should not have to expend effort on a case-by-case basis to perform this assessment. Having an independent certification body where BIM maturity certification is obtained using independent certified assessors (i.e. like ISO) would be simpler for the clients and would better control the quality of the assessment.

2.3 BIM Maturity Assessment for Minimum BIM Certification

The process of BIM capability maturity assessment was used to define a minimum BIM by the National Building Information Model Standard (NBIMS) (2007; 2012). This model is reviewed as follows.

- **NBIMS CMM**

The National Building Information Model Standard (NBIMS) Capability Maturity Model (CMM) (NIBS, 2007) is a tool developed for the strategic management in the BIM implementation of an organization (McCuen et al., 2012). The NBIMS CMM helps users measure their current BIM maturity level, and enables them to plan for future maturity goals (NIBS, 2007). This tool, which is part of the national BIM standard (NIBS, 2007), measures eleven weighted BIM capabilities or area of interest against ten maturity levels. Each area of interest is described in the NBIMS CMM. Figure 2.8 shows the eleven BIM areas of interest with their maturity levels.

Maturity Level	A Data Richness	B Life-cycle Views	C Roles Or Disciplines	G Change Management	D Business process	F Timeliness/ Response	E Delivery Method	H Graphical Information	I Spatial Capability	J Information Accuracy	K Interoperability/ IFC Support
1	Basic Core Data	No Complete Project Phase	No Single Role Fully Supported	No CM Capability	Separate Processes Not Integrated	Most Response Info manually re-collected - Slow	Single Point Access No IA	Primarily Text - No Technical Graphics	Not Spatially Located	No Ground Truth	No Interoperability
2	Expanded Data Set	Planning & Design	Only One Role Supported	Aware of CM	Few Bus Processes Collect Info	Most Response Info manually re-collected	Single Point Access w/ Limited IA	2D Non-Intelligent As Designed	Basic Spatial Location	Initial Ground Truth	Forced Interoperability
3	Enhanced Data Set	Add Construction/ Supply	Two Roles Partially Supported	Aware of CM and Root Cause Analysis	Some Bus Process Collect Info	Data Calls Not In BIM But Most Other Data Is	Network Access w/ Basic IA	NCS 2D Non-Intelligent As Designed	Spatially Located	Limited Ground Truth - Int Spaces	Limited Interoperability
4	Data Plus Some Information	Includes Construction/ Supply	Two Roles Fully Supported	Aware CM, RCA and Feedback	Most Bus Processes Collect Info	Limited Response Info Available In BIM	Network Access w/ Full IA	NCS 2D Intelligent As Designed	Located w/ Limited Info Sharing	Full Ground Truth - Int Spaces	Limited Info Transfers Between COTS
5	Data Plus Expanded Information	Includes Constr/Supply & Fabrication	Partial Plan, Design&Constr Supported	Implementing CM	All Business Process(BP) Collect Info	Most Response Info Available In BIM	Limited Web Enabled Services	NCS 2D Intelligent As-Builts	Spatially located w/Metadata	Limited Ground Truth - Int & Ext	Most Info Transfers Between COTS
6	Data w/Limited Authoritative Information	Add Limited Operations & Warranty	Plan, Design & Construction Supported	Initial CM process implemented	Few BP Collect & Maintain Info	All Response Info Available In BIM	Full Web Enabled Services	NCS 2D Intelligent And Current	Spatially located w/Full Info Share	Full Ground Truth - Int And Ext	Full Info Transfers Between COTS
7	Data w/ Mostly Authoritative Information	Includes Operations & Warranty	Partial Ops & Sustainment Supported	CM process in place and early implementation	Some BP Collect & Maintain Info	All Response Info From BIM & Timely	Full Web Enabled Services w/IA	3D - Intelligent Graphics	Part of a limited GIS	Limited Comp Areas & Ground Truth	Limited Info Uses IFC's For Interoperability
8	Completely Authoritative Information	Add Financial	Operations & Sustainment Supported	CM and RCA capability implemented and	All BP Collect & Maintain Info	Limited Real Time Access From BIM	Web Enabled Services - Secure	3D - Current And Intelligent	Part of a more complete GIS	Full Computed Areas & Ground Truth	Expanded Info Uses IFC's For Interoperability
9	Limited Knowledge Management	Full Facility Life-cycle Collection	All Facility Life-Cycle Roles Supported	Business processes are sustained by CM using RCA and Feedback loops	Some BP Collect&Maint In Real Time	Full Real Time Access From BIM	Netcentric SOA Based CAC Access	4D - Add Time	Integrated into a complete GIS	Comp GT w/Limited Metrics	Most Info Uses IFC's For Interoperability
10	Full Knowledge Management	Supports External Efforts	Internal and External Roles Supported	Business processes are routinely sustained by CM, RCA and Feedback loops	All BP Collect&Maint In Real Time	Real Time Access w/ Live Feeds	Netcentric SOA Role Based CAC	nD - Time & Cost	Integrated into GIS w/ Full Info Flow	Computed Ground Truth w/Full Metrics	All Info Uses IFC's For Interoperability

Figure 2.8 NBIMS CMM Chart
Taken from NIBS (2007)

NBIMS CMM is presented in two versions: Tabular (Figure 2.8) and Interactive (Figure 2.9). The Tabular version is a static Microsoft Excel® workbook including three worksheets of information while the Interactive version is a multi-tab Excel workbook with the same information that interacts with the user entering information and calculations.

In the assessment process, a score, named credit sum, is awarded by adding the perceived maturity level's credit of each area of interest. This approach proposes a minimum score as a threshold to achieve minimum BIM capability. The minimum required score is adjusted yearly by the "National Institute of Building Sciences (NIBS)". If the minimum score is not achieved, it shall not be called BIM. Therefore, the certification will not be achieved and the needed improvements will be specified. As indicated in Figure 2.9, after 'Minimum BIM' level of certification, the other levels, include 'Certified', 'Silver', 'Gold', and 'Platinum', respectively requiring a higher credit sum to be reached, namely 60, 70, 80, and 90.

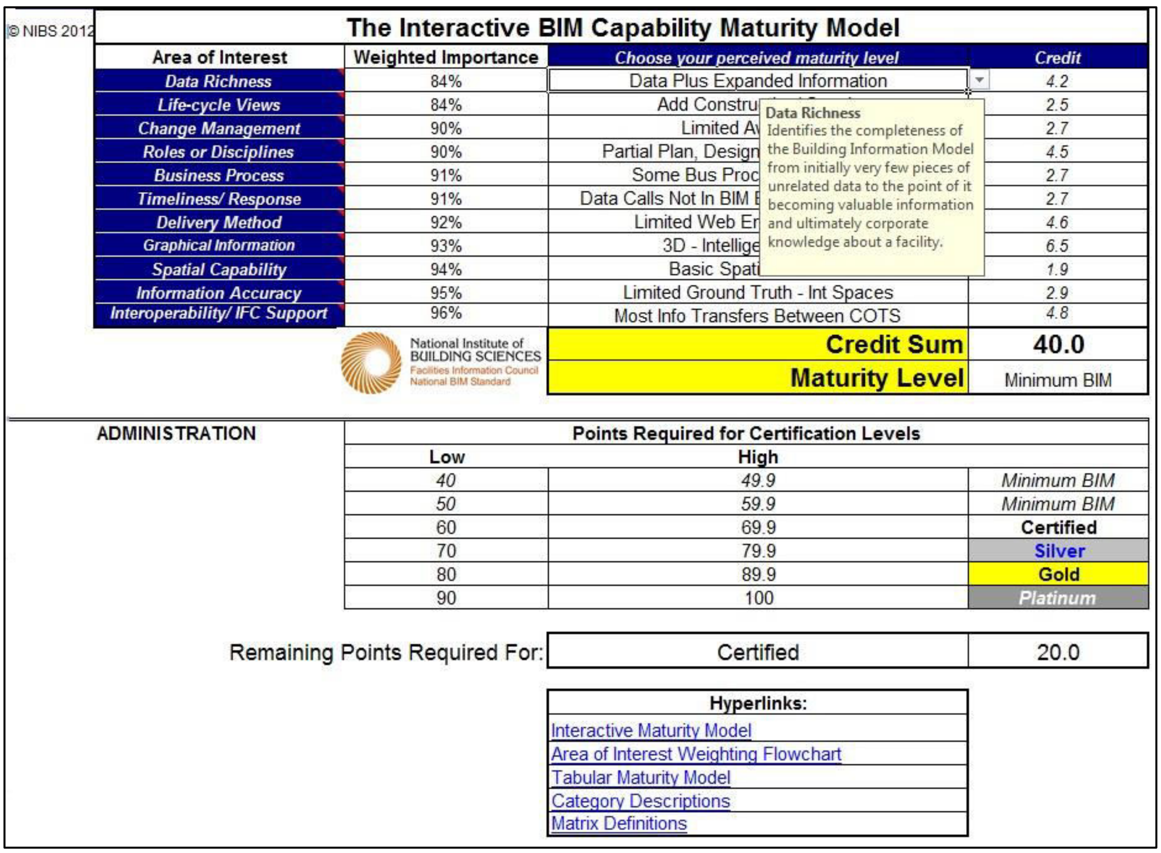


Figure 2.9 Interactive NBIMS CMM
Taken from NIBS (2007)

There are a few critics of NBIMS CMM in the literature. According to Sebastian and Van Berlo (2010) there are several limitations for the use of NBIMS CMM: "It is an internal tool to determine the level of maturity of an individual BIM as measured against a set of pre-defined weighted criteria. CMM is not intended to be used to compare different models or BIM implementations. It is designed to measure the maturity of the model (including the modeling process), but not to measure the BIM maturity of the organization" (Sebastian and Van Berlo, 2010). Succar (2010a) believes that NBIMS CMM has structural limitations that may restrict the usefulness and usability of the model. Existence of ten maturity levels with minimal distinction between them is a weakness (Succar, 2010a), the possible overlap of areas of interest (Suermann et al., 2008 and McCuen, 2007 as cited in Succar, 2010a) are some defects. In addition, Succar (2010a) stated other criticisms, such as "in the Interactive CMM tool an organization or project can achieve a high total score even when they have low scores on some areas of interest". The areas of interest in NBIMS CMM are good to assess models but not useful for teams, organizations or the project teams that generate the models. In addition, this model is only useful for internal self-assessment. The model cannot assess any BIM metric beyond 'information management' and this issue limits its applicability (Succar, 2010a).

2.4 BIM Maturity Assessment for Performance Measurement And Improvement

The BIM Maturity Matrix (BIm³) (Succar, 2010a,b; Succar et al., 2012) and the 'Organizational BIM Assessment Profile' (CIC, 2012) are two models that were developed for the purpose of BIM performance measurement and improvement. These models are reviewed below.

2.4.1 BIM Maturity Matrix (BIm³)

The BIM Maturity Matrix (BIm³) developed by Succar (2010a) "is a knowledge tool which incorporates many BIM Framework components for the purpose of performance measurement and improvement" (Succar, 2010a). Succar et al., (2012) categorize BIM aspects in a hierarchical method with three main sets of technology, process and policy, and their subcategories are expanded in the next levels of hierarchy. These sets of BIM abilities are called 'BIM Competency Sets': "A BIM competency set is a hierarchical collection of individual competencies identified for the purposes of implementing and assessing BIM. In this context, the term competency reflects a generic set of abilities suitable for implementing as well as assessing BIM capability and/or maturity. […] BIM competencies are a direct reflection of BIM requirements and deliverables" (Succar et al., 2012). Succar (2010a) developed a workflow of five steps in order to create a BIM Capability and Maturity Assessment. Figure 2.10 shows a summary of this workflow.

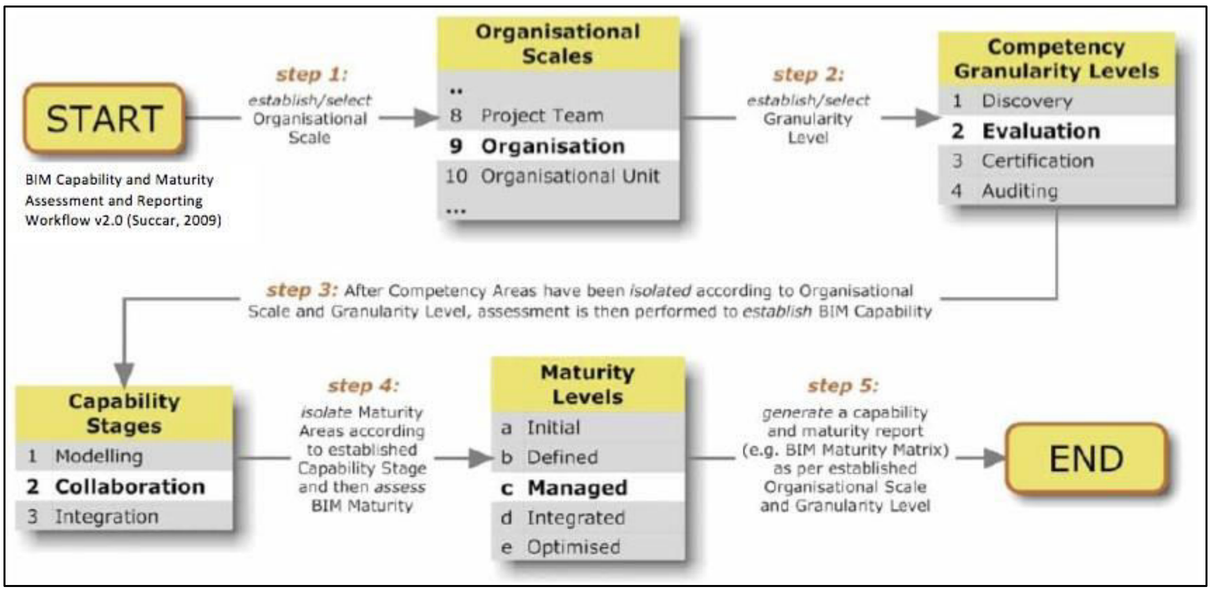


Figure 2.10 BIM capability and maturity assessment and reporting workflow diagram–v2.0 Taken from Succar (2010a) and Succar et al. (2012)

At the first step of the workflow, the user selects the organizational scale (Oscale), intended for assessment, from a table. Using the Oscale filter reduces the number of applicable competencies significantly. At the second step, a four level Granularity filter reduces or increases the number of competency sets for performance assessment by changing the hierarchy level. The user can obtain more detailed competency areas by using higher Granularity Levels (level 3 or 4). At the third step, the assessor selects and isolates the organization (under assessment) 'actual' and 'targeted' capability stages. The BIM capability stages define minimum BIM requirements and are defined in three stages of ‘object-based modeling’, ‘model-based collaboration’, and ‘network-based integration’ respectively. Then, the user assesses if the remaining competencies have achieved ‘minimum capability’. In the fourth step, the assessor separates the BIM competency sets that achieved the minimum capability to assess their maturity. According to Succar et al. (2012), “the term ‘BIM maturity’ refers to the quality, repeatability and degree of excellence within a BIM capability. Although ‘capability’ denotes a minimum ability, ‘maturity’ denotes the extent of that ability in performing a task or delivering a BIM service/product” (p. 124). The five levels of maturity in this model are: (a) Initial/Ad-hoc, (b) Defined, (c) Managed, (d) Integrated and (e) Optimized. Finally, in the last step, the assessment results are reported.

In BIm³, the qualitative descriptions of BIM maturity levels are not specific enough for a quantitative assessment. For example, in the category of ‘Software’ applications, there are some sentences that describe the quality of software usage in maturity levels as follows (Succar, 2010a):

Maturity level 1: “Usage of software applications is unmonitored and unregulated”.
Maturity level 2: “Software usage/introduction is unified within an organisation or project teams (multiple organisations)”.
Maturity level 3: “Software selection and usage is controlled and managed according to defined deliverables”.
Maturity level 4: “Software selection and deployment follows strategic objectives, not just operational requirements”.
Maturity level 5: “Selection/use of software tools is continuously revisited to enhance productivity and align with strategic objectives”.

The problem is that words such as ‘unmonitored’, ‘unregulated’, ‘controlled’ and ‘managed’ can be interpreted in different ways. These maturity metrics may not be accurate and consistent enough, according to Succar (2010b) definitions: Accurate: metrics are clear, verifiable and allow accurate, repeatable assessment; Consistent: when conducted by different assessors, measurements still produce the same results.

2.4.2 Organizational BIM Assessment Profile

The Computer Integrated Construction (CIC) Research Program (2012) at Pennsylvania State University developed "… a standard approach for facility owners to more effectively plan the integration of BIM throughout the organization and the lifecycle of a facility". In addition to facility owners, the other audiences are designers, contractors, operators, and consultants who advise owners. This guide defines three specific procedures or methods for owners to develop their BIM plans. These procedures include 'BIM Organizational Strategic Planning', 'Owner BIM Organizational Execution Planning', and 'Owner BIM Project Procurement Planning'. The 'BIM Organizational Strategic Planning' allows an owner to understand why and how BIM can be integrated in an organization. With this procedure, firstly, the maturity of the different aspects of an organization, which are critical for its BIM implementation, are measured. To assess these aspects, which are called BIM planning elements (Figure 2.11), the planning committee uses the Organizational BIM Assessment Profile (Figure 2.12).

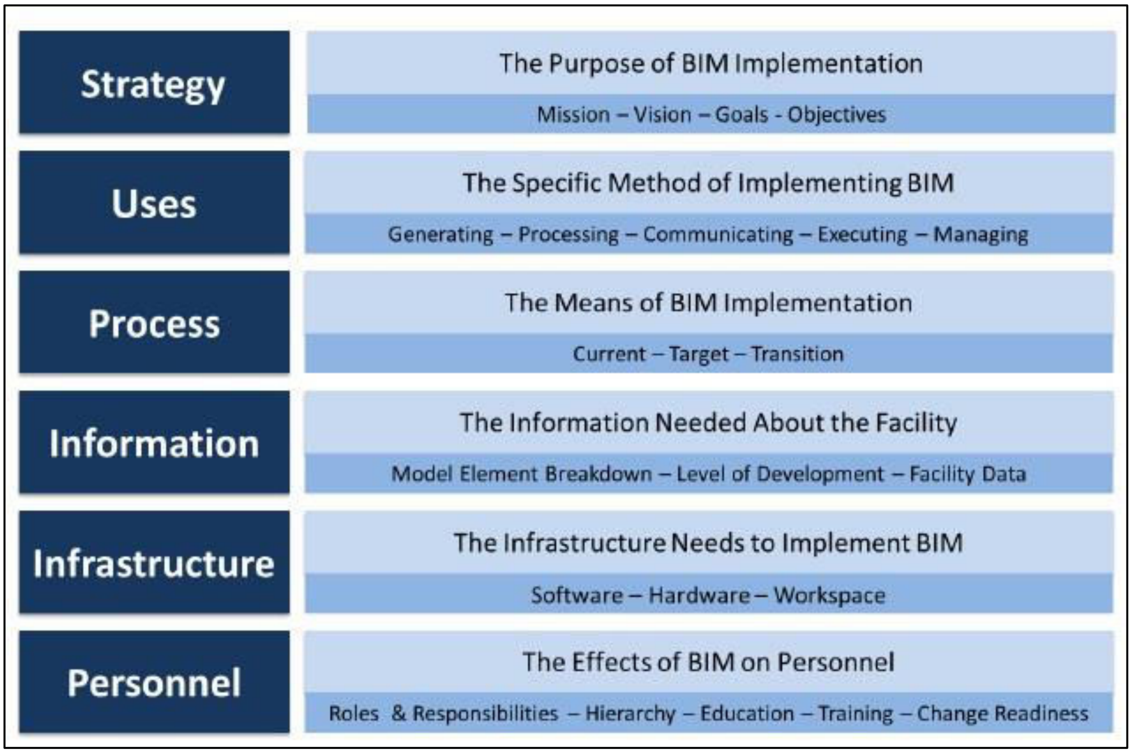


Figure 2.11 The BIM planning elements
Taken from CIC (2012)

As shown in Figure 2.11, six BIM planning elements, including strategy, BIM Uses, processes, information, infrastructure, and personnel, are introduced in a table. For assessment of BIM planning elements, they are broken up into a total of 20 sub-categories as demonstrated in the Organizational BIM Assessment Profile (Figure 2.12). In this matrix, the planning elements and their sub-categories are described. Each one of the 20 sub-categories is measured against six maturity levels. On each maturity level there is a basic description for each sub-category of planning elements. A value is assigned to each maturity level, which enables the profile to calculate the total score of maturity.

By establishing 'current' and 'target' maturity levels, the Organizational BIM Assessment Profile (Computer Integrated Construction Research Program, 2012) provides a new approach in using maturity assessment for performance improvement. Future research can be conducted on the transition from 'current' to 'target' maturity levels in a project. However, there is not much detail provided within the matrix to describe the different maturity levels or the subcategories.

2.5 Analysis of Contributions to This Study

How do these different models fit the characteristics outlined for this study? To answer this question current BIM maturity models will be studied, in detail, using quality criteria to assess how they can contribute to the design of a detailed BIM maturity model. April (2005) has proposed quality criteria to assess the validity of existing maturity model proposals. Inspired by this approach, the following were establisehd to assess whether a current BIM maturity proposals can contribute to the design of our model:

Criterion 1- “Yes: detailed practices are available, No: practices are private or only a general framework is proposed that doesn’t include detailed practices”;

Criterion 2- “Yes: established model, No: experimental/research model, marginal or obsolete content”;

Criterion 3- “Yes: recent publications which demonstrate the model’s popularity and industry interest, No: no important or recent publication (other than the author’s) or demonstrated industry interest”;

Planning Element	Description	Level of Maturity						Current Level	Target Level	Total Possible
Strategy	the Mission, Vision, Goals, and Objectives, along with management support, BIM Champions, and BIM Planning Committee.	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	11	17	25
Organizational Mission and Goals	A mission is the fundamental purpose for existence of an organization. Goals are specific aims which the organization wishes to accomplish.	No organizational mission or goals	Basic organizational mission established	Established basic organizational goals	Organization mission which addressed purpose, services, values (at a minimum)	Goals are specific, measurable, attainable, relevant, and timely	Mission and goals are regularly revisited, maintained and updated (as necessary)	1	3	5
BIM Vision and Objectives	A vision is a picture of what an organization is striving to become Objectives are specific tasks or steps that when accomplished move the organization toward their goals	No BIM vision or objectives defined	Basic BIM vision is establish	Established Basic BIM Objectives	BIM Vision address mission, strategy, and culture	BIM objectives are specific, measurable, attainable, relevant, and timely	Vision and objectives are regularly revisited, maintained and updated (as necessary)	2	3	5
Management Support	To what level does management support the BIM Planning Process	No management support	Limited support for feasibility study	Full Support for BIM Implementation with some resource commitment	Full support for BIM Implementation with appropriate resource commitment	Limited support for continuing efforts with a limited budget	Full support of continuing efforts	3	4	5
BIM Champion	A BIM Champion is a person who is technically skilled and motivated to guide an organization to improve their processes by pushing adoption, managing resistance to change and ensuring implementation of BIM	No BIM Champion	BIM Champion identified but limited time committed to BIM initiative	BIM Champion with adequate time commitment	Multiple BIM Champions with each working Group	Executive Level BIM Support Champion with limit time commitment	Executive-level BIM Champion working closely with working group champion	3	4	5
BIM Planning Committee	The BIM Planning Committee is responsible for developing the BIM strategy of the organization	No BIM Planning Committee established	Small Ad-hoc Committee with only those interested in BIM	BIM Committee is formalized but not inclusive of all operating units	Multi-disciplinary BIM Planning Committee established with members from all operative units	Planning Committee includes members for all level of the organization including executives	BIM Planning decisions are integrated with organizational Strategic Planning	2	3	5
BIM Uses	The specific methods of implementing BIM	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	2	5	10
Project Uses	The specific methods of implementing BIM on projects	No BIM Uses for Projects identified	Minimal owner requirements for BIM	Minimal BIM Uses required	Extensive use of BIM with limited sharing between parties	Extensive use of BIM with sharing between parties within project phase	Open sharing of BIM data across all parties and project phases	1	3	5
Operational Uses	The specific methods of implementing BIM within the organization	No BIM Uses for Operations identified	Record (As-Built) BIM model received by operations	Record BIM data imported or referenced for operational uses	BIM data manually maintained for operational uses	BIM data is directly integrated with operational systems	BIM data maintained with operational systems in Real-time	1	2	5
Process	The means by which the BIM Uses are accomplished	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	2	5	10
Project Processes	The documentation of External Project BIM Processes	No external project BIM processes documented	High-level BIM process documented for each party	Integrated high-level BIM process pocumented	Detailed BIM process documented for primary BIM Uses	Detailed BIM process documented for all BIM Uses	Detailed BIM process documented and regularly maintained and updated	1	3	5
Organizational Processes	The documentation of Internal Organizational BIM Processes	No internal organizational BIM processes documented	High-Level BIM process documented for each operating unit	Integrated High level organizational process documented	Detailed BIM process documented for primary organizational Uses	Detailed BIM process documented for all BIM Uses	Detailed BIM Process documented and regularly maintained and updated	1	2	5

Figure 2.12 Organizational BIM Assessment Profile
Taken from CIC (2012)

Criterion 4- Yes: adapted (fully or partially) to construction industry characteristics, No: Not adapted to construction industry characteristics.

Criterion 5- Yes: includes the notion of BIM use, No: Doesn't include any notion of BIM use.

Planning Element	Description	Level of Maturity						Current Level	Target Level	Total Possible
Information	Information Needs refer to Model Level of Development and Facility Data requirements	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	6	10	15
Model Element Breakdown (MEB)	Model Element Breakdown Structure are identifiers assigned to each physical or functional element in the breakdown of the facility model.	No consistent Organizational Model Element Breakdown	Organizational Model Element Breakdown defined but not uniform within entire organization	Organizational Model Element Breakdown is uniform within the organization	Organizational Model Element Breakdown aligned with industry standards	Organizational Model Element Breakdown updated along with industry standards	Organizational modifications to industry standard model element breakdown are balloted for inclusion in industry standards	1	3	5
Level of Development (LOD)	The Level of Development (LOD) describes the level of completeness to which a Model Element developed	No consistent Level of Development	LOD defined but not standardized witin the entire organization	LOD standardized within the organization	Organizational LOD standards aligned with industry standards	Model View Definitions & Information Delivery Manuals are used to define LOD	Organizational modification to MVDs and IDMs are balloted for inclusion in industry standards	2	3	5
Facility Data	Facility Data is non-graphical information that can be attached to objects within the Model that defines various characteristics of the object	No consistent facility data requirement	Facility data defined but not internally standardized	Facility data defined and standardized within the organization	Organizational facility data attributes aligned with industry standards	Facility data attributes aligned with open standards	Facility data attributes updated with open standards	3	4	5
Infrastructure	Technological and physical systems needed for the operation of BIM with the organization.	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	5	9	15
Software	the programs and other operating information used by a computer to implement BIM	No BIM Software	Software capable of accepting BIM data	Facility data defined and standardized within the organization	Advanced BIM software systems	All software systems available to all personnel	Program established for continous updating of BIM software systems	2	3	5
Hardware	physical interconnections and devices required to store and execute (or run) BIM software	No Hardware capable of running BIM software	Some hardware capable of running basic BIM software	Facility data defined and standardized within the organization	Some advanced hardware systems with the organzation	All organization hardware is capable of running advanced BIM Software	Program established for continous updating of BIM hardware systems	2	4	5
Physical Spaces	Functional areas within a facility used to properly implement BIM within the organization	No dedicated BIM space	Single workstation for viewing BIM data	Facility data defined and standardized within the organization	BIM room for collaborating with large screen viewing capability	Multiple collaborative workspaces within regular workspace	Program established for continous updating of BIM spaces	1	2	5
Personnel	Human resources of an organization	0 Non-Existent	1 Initial	2 Managed	3 Defined	4 Quantitatively Managed	5 Optimizing	9	15	25
Roles and Responsibilities	Roles are the primary function assumed by a person within the organization and Responsiblities are the tasks or obligations that one is required to do as part of that role.	No roles and responsibilities documented	BIM is the responsibility of the BIM Champion	BIM is the responsibility of the interdisciplinary BIM Group	BIM responsibility lies with each operating unit	BIM responsibility lies with each person	BIM Responsiblities are regularly reviewed to ensure they are properly distributed	2	3	5
Organizational Hierarchy	An arrangement of personnel and group into functional groups within the organization	Organizational Hierarchy does not address BIM	BIM Champion outside of typical organizational hierarchy	Small BIM Implementation Team outside the typical organization hierarchy	Large interdisciplinary BIM Group created	BIM Champion defined within each operating unit	BIM Implemenation Team supports BIM Use within operating units	1	3	5
Education	Education is to formally instruct about a subject	No Education Program	Ad hoc education as needed	Formal Presentations on what is BIM and the Benefits	Regularly conducted employee education	On-Demand education program established for	Education is seemlessly improved through lessons learned	1	2	5
Training	Train is to teach so as to make fit, qualified, or proficient in a specific task or process	No Training Program	Training program run by vendors - only for necessary personnel	Internal Training program for all personnel that may interact with BIM	Regularly conducted and routine training programs	On-Demand training program established for the organization	Training is seemlessly improved through lessons learned within the organization	3	4	5
Change Readiness	The willingness and state preparedness of an organization to integrate BIM	No Change Readiness Awareness	Established need for BIM	Upper management buy-in	Operating unit buy-in	All individuals buy-in	Willingness to change is part of the culture of the organization	2	3	5
Totals	This is the total for all the categories. Note this does reflect maturity in all sections. While the organization could score high, there could be some key areas not implemented that could hinder the organizations BIM Implementation.							33	56	90

Figure 2.12 (continued) Organizational BIM assessment Profile
Taken from CIC (2012)

Table 2.2 shows, for seven BIM Maturity Models, whether or not they meet the quality criteria.

Table 2.2 BIM Maturity Models evaluation according to the four criteria

Model	**Criterion 1**	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**
BIM Quick Scan (Sebastian & Van Berlo, 2010)	Yes	Yes	Yes	Yes	No
IU BIM Proficiency Matrix (Indiana University, 2012)	Yes	Yes	Yes	Yes	Yes
Organizational BIM Assessment Profile (CIC, 2012)	Yes	Yes	Yes	Yes	Yes
NBIMS Capability Maturity Model (NIBS, 2007; 2012)	Yes	Yes	Yes	Yes	No
BIM Maturity Matrix (BIm³) (Succar, 2010a,b; Succar et al., 2012)	Yes	No	Yes	Yes	No
BIM Qualifications Scoring Matrix (CIC, 2012)	Yes	Yes	Yes	Yes	No
BIM Proposal Scoring Matrix (CIC, 2012)	Yes	Yes	Yes	Yes	Yes

All the models presented in Table 2.2 have detailed practices (criterion 1). This is useful to map them to the proposed model of this research, where applicable. They are also established and deployed (criterion 2), as a complete model, except the BIM Maturity Matrix (BIm³) (Succar, 2010a,b; Succar et al., 2012), which is not complete and its development is still in progress. All of these models are recent and developed in the recent years (criterion 3). All these models are developed for construction industry. Therefore they all meet criterion 4.

Only three models presented in Table 2.2 meet the criteria and incluce a notion of BIM uses (criterion 5). Consequently, three models and other relevant sources can be used for our research to design a novel BIM Use Maturity Model (BIMUMM) focused on BIM Uses. This research methodology is described in the next chapter.

CHAPTER 3

METHODOLOGY

This chapter presents the methodological approach of this research. Defining the research question and objective is the first step to any research. The proposed method for model development undertaken is presented. Model validation is the last step of this research.

3.1 Research Methodology

This research is composed of four distinct stages, as described below:

Stage 1: Definition of problem and research steps

In this step, the research question, objective, and methodology were determined.

Stage 2: Literature Review

Through literature review, two topics are studied: 1) BIM definitions, uses areas, and benefits, 2) Maturity models, in the domain of BIM and other domains. The inventory of maturity models relevant to this research will be provided and selected models will be studied in depth, described and critically analyzed.

Stage 3: Model Development

At this stage, the proposed model architecture will be designed. This includes identification of the BIM domains, Key Process Areas (KPAs), and practices. The practices will be mapped iteratively, from the source documents to the model.

Stage 4: Model Verification and Validation

The developed model will be discussed in a focus group meeting with industrial and academic experts in the field of BIM. The possible improvements will be considered and the model will be updated.

The research stages are summarized in Table 3.1.

Table 3.1 Research Methodological approach
Adapted from April (2005)

Stage 1: Definition of problem and research stages		
Research Question	**Research Objective**	**Methodology**
How can the current BIM maturity models evolve to develop a BIM maturity model for construction project clients to pre-qualify project applicant firms in BIM?	To develop a prototype BIM Uses Maturity Model for BIM pre-qualification assessment of project applicants	- Literature review -Model development by iterative mapping - Model verification and validation by focus group meeting
Stage 2: Literature Review		
Objective	**Topics**	**Results**
To study BIM and maturity models in BIM and other areas	-Literature review of BIM -Literature review of maturity models	-BIM definition, Uses, and benefits; -Selection, description and critical analysis of seven BIM maturity models; -Identify and present BIM maturity assessment categories; -Analysis of contribution of the seven selected models to this study; -Selection, description, and adaptation of a maturity model from software industry.

Table 3.1 (continued) Research methodological Approach
Adapted from April (2005)

Stage 3: Model Development		
Objective	**Execution**	**Results**
To design the model architecture and content	-Development of the maturity model architecture. -Mapping BIM maturity assessment categories from different sources to define the proposed KPAs and Roadmaps of the maturity model; -Mapping/adjusting the detailed BIM practices to develop a first version of the BIM Uses Maturity Model (BIMUMM).	-Presentation of BIM Uses Maturity Model (BIMUMM) objective, scope, and its architecture, including BIM domains, Key Process Areas (KPAs), Roadmaps and practices; -Proposing the model's maturity scale, and evaluation process -Development of model content, including detailed practices and their corresponding assessment questions.
Stage 4: Model verification and validation		
Objective	**Method**	**Results**
To verify and validate the proposed model	-Focus group meeting	-Opinion of industrial and academic BIM experts is collected regarding the proposed model -Their recommendations are considered for revision and improvement of model.

3.2 Proposed Model Development Activities

This section explains the procedure used in this research to design and iteratively build the proposed BIM Uses Maturity Model (BIMUMM).

The steps of development are described in Figure 3.1.

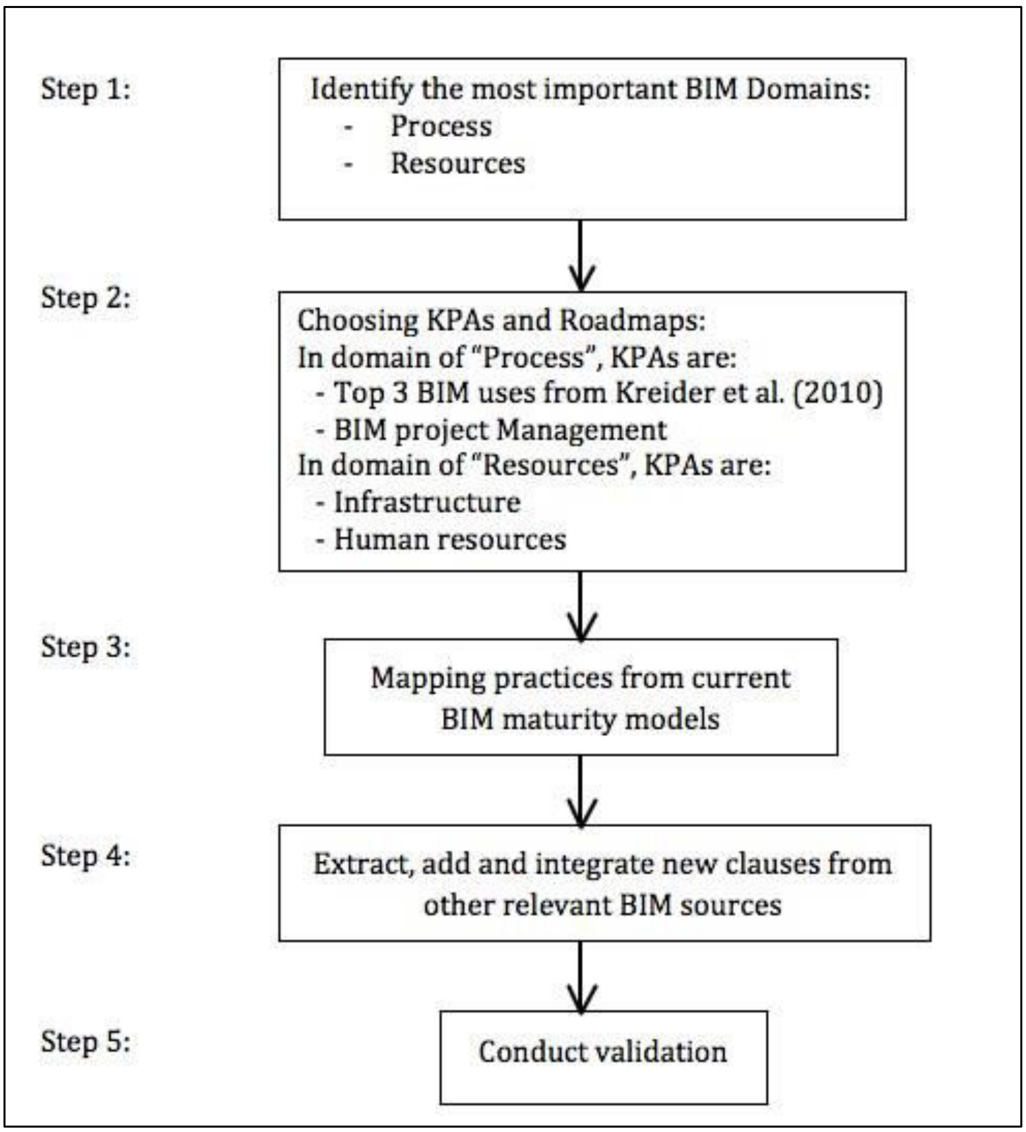


Figure 3.1 BIM Uses Maturity Model (BIMUMM) development steps
Adapted from April and Coallier (1995)

Through the literature review, studies are done in the context of research. The literature review is focused on BIM and maturity models, and through analysis, the sources are used in order to design the architecture of the proposed model. Model development from literature analysis corresponds to steps 1 to 4 of Figure 3.1. After model development, the model is validated.

These steps are used to integrate practices as follows (adapted from April and Coallier, 1995):

1- BIM domains of 'Process' and 'Resources' are chosen as the target BIM domain of this study.

2- Each BIM domain has its own KPAs. The domain of 'Process' includes the top three most frequent uses of BIM KPAs, selected from Kreider et al. (2010), plus the KPA of 'Project management'. The KPAs in the domain of 'Resources' are 'Infrastructure' and 'Human resources'.

3- The practices are mapped from current BIM maturity models (Succar, 2010a,b; Succar et al., 2012; Sebastian and Van Berlo, 2010; Computer Integrated Construction Research Program, 2012; Indiana University, 2012; NIBS, 2007, 2012) to embed BIM maturity levels of defined roadmaps.

4- The practices from other relevant BIM resources that do not exist in the current BIM maturity models are extracted, added and integrated.

5- The resulting model will be iteratively validated with industry experts through focus group meetings to readjust the roadmaps, KPAs, and practices.

In steps 4 and 5, the detailed practices are developed.

3.3 Model Validation

For model validation, the focus group method is chosen. By conducting a focus group, the researcher aim to listen and gather information and the opinion of participants regarding an issue, product, or service. Selection of participants is based on their common characteristics related to the particular topic of the focus group. The participants constitute a special type of group in terms of purpose, size, composition and procedures. The researchers provide a permissive environment within the focus group and encourage participants to share their perceptions and perspectives without any pressure to vote or reach consensus. Then researchers perform careful and systematic analysis of discussions to find out how a product, service or opportunity is perceived by the participants (Krueger & Casey, 2009). The reasons for choosing this method are (adapted from Krueger & Casey, 2009):

a) The researchers can see the issue through the eyes of the target audience. In this research, the maturity model is supposed to be used for the evaluation of construction project applicants. Therefore, the audiences, which are project applicants, should be invited to the focus group.

b) By conducting the focus group, the researcher can collect qualitative data that is of interest for them. The questions are more general at the beginning, and become more specific as the focus group meeting continues. BIM maturity model development requires more qualitative data and a focus group is a suitable method for collecting it.

c) A focus group is a helpful method in developing and maintaining quality improvement efforts. Therefore it meets one of the goals of BIM maturity models, which is improvement of BIM processes.

In the focus group meeting, the researcher presents the proposed BIM Uses Maturity Model v.0 and asks the participants to give their opinions about the model architecture and content. Based on the feedback, the researcher modifies the model by iteratively analyzing the information and with more review of literature. The validation process is shown in Figure 3.2. More information about the validation step is provided in the last chapter.

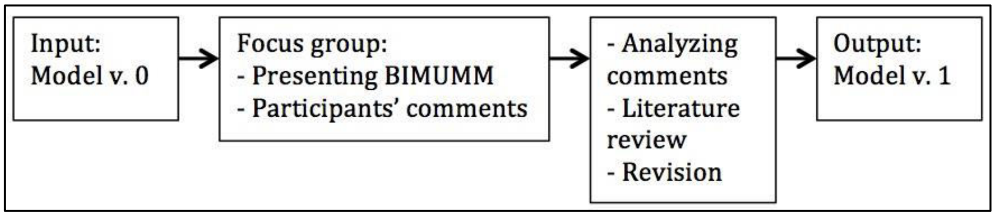


Figure 3.2 BIMUMM validation process

3.4 Conclusion

The research approach is based on four stages. At the first stage, research question and objective is defined, and research methodology is developed. The second stage includes review of literature about BIM and maturity models. This stage helps the researcher learn about these subjects and use the literature to reach the objective of research, which is development of a prototype BIM Uses Maturity Model (BIMUMM) for BIM pre-qualification assessment of project applicants. At third stage of this research, model development starts. The proposed architecture of BIMUMM and its content is developed in this stage. The main components of BIMUMM include BIM domains, Key Process Areas (KPAs), Roadmaps, and Practices. At this stage, the model maturity scale and evaluation process are also proposed. Fourth stage of this research is model verification and validation. Opinion of industrial and academic BIM experts regarding the proposed model is collected for model revision and improvement.

Chapter 4 presents the proposed perspective and architecture of BIMUMM, and also proposed maturity scale and evaluation process. The results of the model development mapping from different resources are presented in chapters of 5 and 6. The proposed model is a prototype or concept of operations, which will need to be tested in future researchs. The model validation process and results are explained in chapter 7.

CHAPTER 4

PROPOSED BIM USES MATURITY MODEL (BIMUMM) FOR INDEPENDENT CERTIFICATION

Construction clients need a way to ensure that the participating firms of the project meet minimum BIM requirements to qualify for the project. From the perspective of a client, ‘minimum BIM qualification’ can be translated to ‘minimum capability to use BIM’ and this is practically what is wanted from a certification: ‘how well does this participant use BIM technology in a construction project?’. This is accepted as the principal assumption of this study. Clients want to know whether a firm is capable of using BIM, and if yes, to what level. This perspective offers an opportunity to adapt existing BIM maturity models to reach that goal. Current BIM maturity models do not consider BIM in this way. The existing BIM maturity models provide a rich base of information to achieve this goal. However, no model has focused on the development of maturity levels of ‘BIM Uses’: “A BIM Use is a unique task or procedure on a project which can benefit from the integration of BIM into that process” (CIC, 2011, p. 1). This research proposes a new approach in assessing the BIM capability maturity of firms in performing specific BIM Uses, while measuring their general BIM competencies at the same time. This approach fits better with a clients’ expectation from a maturity model because they want to know how well a project stakeholder uses BIM to deliver a BIM product or service. Therefore, it is stipulated that a BIM uses maturity model that provides information about the maturity of BIM Uses could better meet client expectations.

4.1 Proposed Perspective

Client perpective is also considered in other industries. Kärkkäinen et al. (2012) added “customer dimension” in maturity models of Product Lifecycle Management (PLM) and defined preliminary maturity level description, in five levels, for this dimesion. PLM is described as effective lifecycle management of products (Stark, J., 2011). PLM and BIM have similarities and differences. For example, both aim to "integrate people and data processes throughout the design, construction and operation of a product (or built asset)" (Jupp & Singh, 2014, p. 38). However, "PLM in manufacturing is therefore a more proven lifecycle integration solution. In construction, even despite BIM-enabled IPD approaches, the flow and management of information is still not fully integrated among all stakeholders." (Jupp & Singh, 2014, p. 39). In addition, the main reason that PLM maturity is not studied in depth for this research is that it is not adapted to construction industry characteristics and doesn't incluce BIM uses, as the main focus of this research.

The software industry has considerable experience in adopting capability maturity models from the quality management field to software industry processes (i.e. Capability Maturity Model Integration (CMMI)). Although processes in the software industry are quite different from processes in the construction industry, the notion of process maturity is the same. To develop the proposed model in this study, a maturity model from the software industry, namely Software Maintenance Maturity Model-S^{3M} (April, 2005) has been studied, which is based on the client perspective and is designed from using both industry references, and national and international standard practices. This model helps software "maintainers identify their process maturity level and guide them to higher maturity processes…. The maintenance maturity model was developed to address the uniqueness of software maintenance" (April, 2005, p. 143). S^{3M} uses the architecture of the CMMI (SEI, 2010a) and draws upon practices from two international software standards: ISO 12207 and ISO 14764. The reason that S^{3M} is studied here is that the relation of our proposed maturity model to the other BIM maturity models (i.e. IU and CIC) is a similar relation of that of S^{3M} to CMMI. S^{3M} maps practices from CMMI and ISO standards in the same way that our proposed model maps to several BIM maturity models (i.e. Succar, 2010a,b; Succar et al., 2012; Sebastian and Van Berlo, 2010; CIC, 2012; Indiana University, 2012; NIBS, 2007, 2012) to cover unique client expectations (BIM Uses).

4.2 Proposed Architecture

April (2005) organizes software maintenance activities in a hierarchical architecture from most general definitions to most specific practices. The first level of this hierarchy (less specific) to the fourth level (most specific) includes “Domains”, “Key Process Areas (KPAs)”, “Roadmaps”, and “Practices” respectively. The proposed BIM uses maturity model is inspired from the S^{3M} architecture as shown in Figure 4.1 and a detailed view of the proposed architecture is presented in Figure 4.2.

Domains ⊂	KPAs ⊂	Roadmaps ⊂	Practices
Level 1	Level 2	Level 3	Level 4

Figure 4.1 Proposed BIM Uses Maturity Model (BIMUMM) architecture overview
Adapted from April (2005)

4.2.1 BIM Domains

This research develops BIMUMM based on the domains of “BIM Processes” and “BIM Resources” as they pertain to the construction industry to address the construction clients concern regarding the assessment of minimum BIM capabilities of applicants to their projects. The “BIM Processes” domain considers BIM capabilities regarding specific “BIM Uses” and the maturity level of BIM project management. This domain is very important as a client wants to know how well a firm is using and managing BIM technology in this area. The “BIM resources” domain evaluates the required resources to perform the BIM Processes in general. The available resources of applicants are an important factor for project team selection from the perspective of the construction clients.

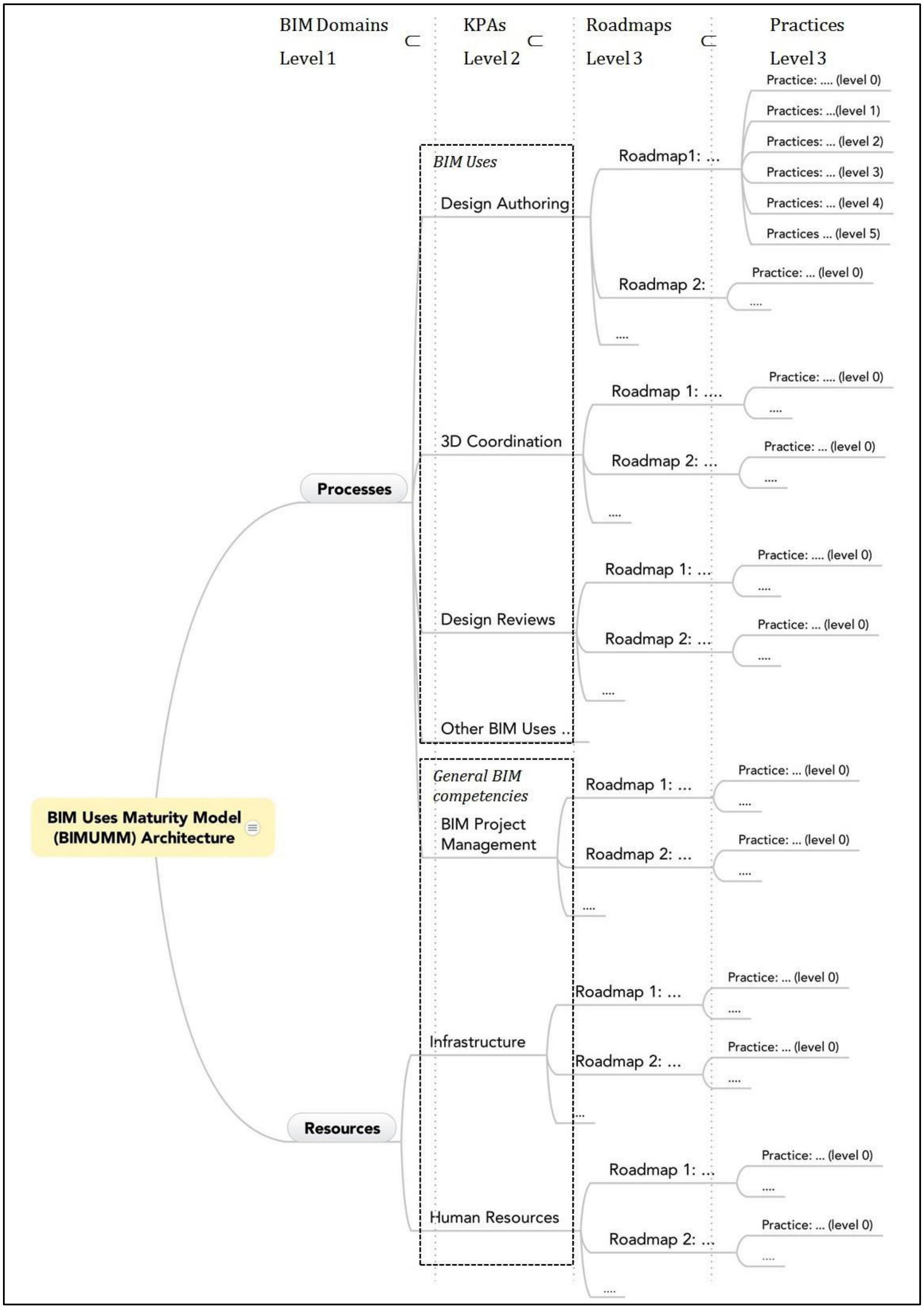


Figure 4.2 A detailed view of proposed architecture of the BIM Uses Maturity Model (BIMUMM)

4.2.2 Key Process Areas (KPAs)

In this research, KPAs of the 'BIM Process' domain include BIM Uses and project management. BIM Uses are about specific practices of BIM in construction projects. The top three most frequent uses of BIM, which include '3D Coordination', 'Design Reviews', and 'Design Authoring' according to Kreider et al. (2010) study, are selected to introduce an example of BIM Use specific KPAs in the proposed BIM uses maturity model (Figure 4.3).

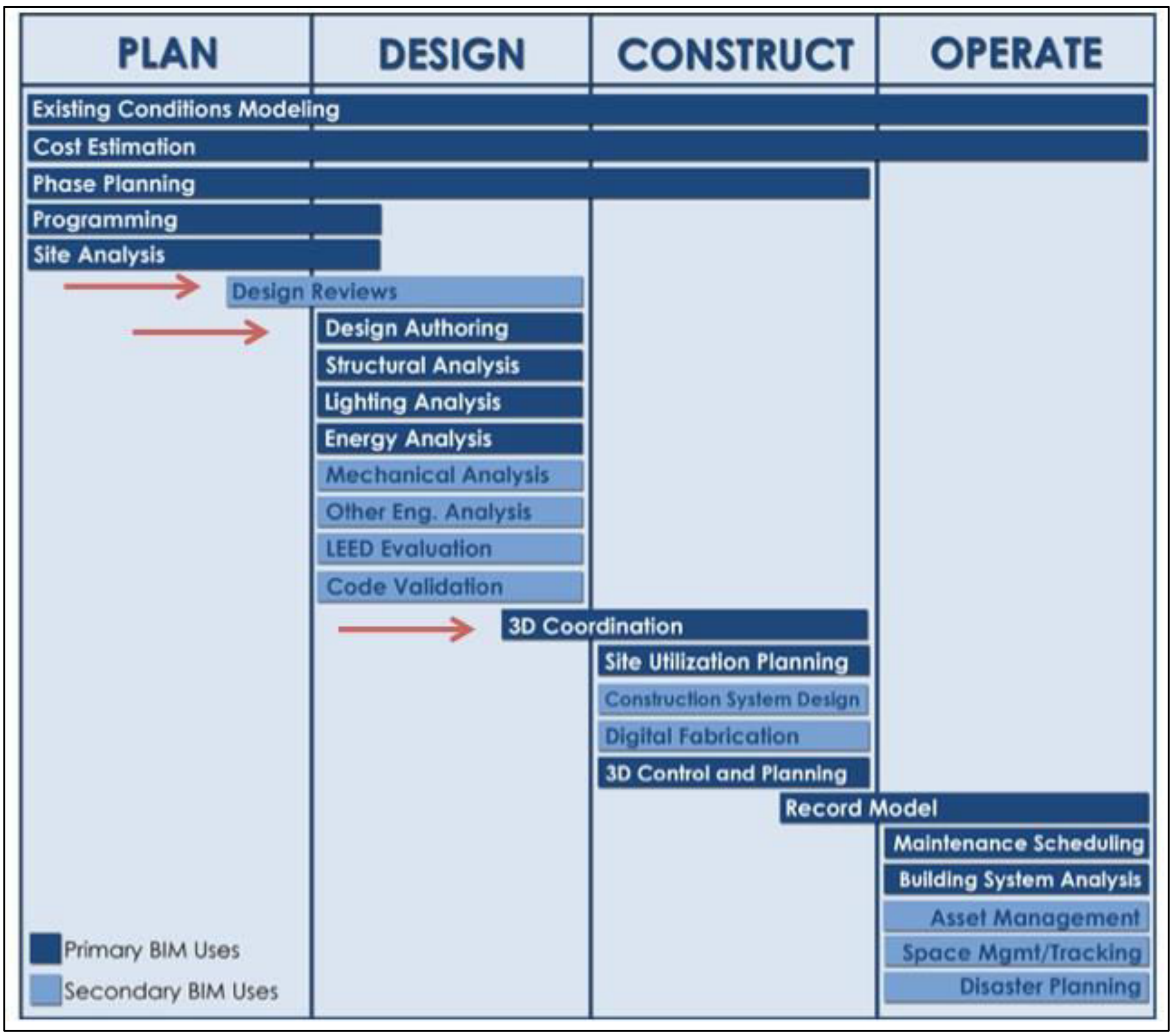


Figure 4.3 Selected BIM Uses for BIMUMM
Adapted from CIC (2011)

The proposed ‘BIM project management’ KPA refers to the quality of management in using BIM. It is known that BIM project management can include various activities, such as designing a BIM execution plan in project, defining and procuring required BIM resources, and defining BIM collaboration processes, etc. The proposed ‘BIM Resources’ domain includes KPAs related to BIM ‘infrastructure’ and ‘human resources’. In other words, the allocated infrastructure and human resources to BIM at the organization/project levels will be assessed in this domain and within these KPAs. The proposed maturity model considers BIM infrastructure as the technological aspects of BIM (i.e. software, hardware, network). It is also known that human resources relates to the personnel roles and responsibilities, and the level of knowledge, skill, and experience that they posses, in using BIM technologies. The training and educational programs of an organization used to improve the BIM competency of personnel will be evaluated in this category. In the proposed maturity model, KPAs are also categorized according to both their general and specific BIM capabilities. Since a ‘BIM Use’ is about mastering BIM practices in a doing a task in a project, KPAs of ‘BIM Uses’ are considered as specific BIM capabilities. Because KPAs of ‘Project management’, ‘Infrastructure’ and ‘Human resources’ do not reflect any specific BIM application, they are defined, in the proposed maturity model, as part of a ‘General BIM competency’ category.

4.2.3 Roadmaps and Practices

A roadmap is defined “ … as a set of linked practices that can often cover many levels of maturity” (April 2005, p. 76). Each KPA contains a number of roadmaps. Practices are defined within the roadmaps: “In a given roadmap, the sequencing of the practices is organized based on the sequencing of the pre-requisites required to move from an initial beginner’s implementation of a process up to its mastery. Practices required to initiate the implementation process are positioned at the initial level (e.g. level 1), while more sophisticated practices are ordered progressively up to level 5.” (April, 2005). In the proposed BIM uses maturity model, the practices are mapped from current BIM maturity models (Succar, 2010a,b; Succar et al., 2012; Sebastian and Van Berlo, 2010; Computer Integrated Construction Research Program, 2012; Indiana University, 2012; NIBS, 2007,

2012) and other relevant sources. BIM experts meet to discuss the position and the rationale of each practice in the maturity levels, and possible improvements. Based on the obtained feedback, an iterative development of the proposed maturity model (iterative model development/improvement and experts' feedback) is carried out.

4.3 Proposed Maturity Scale

As many maturity models use a five-level scale of maturity and some models add level 0 to have six-level scale (see Succar et al., 2012, p. 134), the proposed model also proposes a six-level scale. However, the proposed model of this research is developed from maturity levels 0 to 2, and the levels 3 to 5 is considered for future researchs. The maturity scale of the BIM Planning guide for facility owners (CIC, 2012), which used BIM maturity level definitions inspired from the Capability Maturity Model Integration (CMMI) for Services (Forrester et al., 2011) (Figure 4.4) is adopted for BIMUMM. Each KPA can be assessed against a maturity scale of six levels (levels 0-5). Reaching a maturity level requires the achievement of all the practices of that level.

However, the BIM maturity assessment measurement is inspired from the ISO 15504 recommendation in four categories: N, P, M and F. The S^{3M} (April, 2005) and many other maturity models conform to this ISO recommendation that defines partial maturity of a practice when it is not fully achieved or not achieved (ISO/IEC15504):

N: Not reached – 0 to 15%
P: Partially reached – 16%-50%
M: Mostly reached – 51%-85%
F: Fully reached – 85%-100%

Maturity Level	Description
(0) Non-Existent	At this maturity level, a process has not yet been incorporated into current business processes and does not yet have established goals and objectives.
(1) Initial	At this maturity level, a process produces results in which the specific goals are satisfied, however, they are usually ad hoc and chaotic. There is no stable environment to support processes with the inability to repeat such and possible abandonment in time of crisis.
(2) Managed	At this maturity level, a process is planned and executed in accordance with policy; employs skilled people having adequate resources to produce controlled outputs; involves relevant stakeholders; is monitored, controlled, and reviewed; and is evaluated for adherence to its process description.
(3) Defined	At this Maturity level, a process is tailored to the organization's standard processes according to the organization's guidelines; has a maintained process description; and contributes process related experiences to the organizational process assets
(4) Quantitatively Managed	A this maturity level, a process is managed using statistical and other quantitative techniques to build an understanding of the performance or predicted performance of processes in comparison to the project's or work group's quality and process performance objectives, and identifying corrective action that may need to be taken.
(5) Optimizing	At this maturity level, a process is continually improved through incremental and innovative processes and technological improvements based on a quantitative understanding of its business objectives and performance needs and tied to the overall organizational performance.

Figure 4.4 BIM Maturity Levels
Taken from CIC (2012)

To enable the maturity assessment of practices, the presence and the reached level of each practice, namely N, P, M, or F, is asked in form of a question. The questions for maturity level zero are close-ended and can be answered by 'Yes' or 'No'. But the questions for higher levels can be answered with N, P, M, or F. If the answer to the level zero question is 'No', then no more questions will be asked for higher levels.

4.4 Proposed Evaluation Process

To assess the BIM maturity level of a participant, an assessment tool should be developed, to calculate a threshold rating, which would represent a BIM entry level to be eligible to participate in a construction project requiring BIM uses. The applicants could be assessed for eligibility and could present their maturity certificate when bidding on a construction project. A certified BIM maturity assessor (i.e. an independent assessment body) could issue the certificate. The BIM maturity assessment could take place at any time. As mentioned before, based on the situation of BIM in the firm, a respondent could be assessed using a questionnaire that would rate each BIM use practice as ‘Not reached’, ‘Partially reached’, ‘Mostly reached’, and ‘Fully reached’. To achieve a maturity level, all practices of a level must be ‘Fully reached’. Finally, independent assessment bodies could ensure independence for a BIM maturity assessment results and can issue certificates. Figure 4.5 presents a sample hypothetical report, showing the result of a BIMUMM assessment.

BIM Domains	KPAs	Level 0 Question	Rating	Level 1 Questions	Completed	Rating	Level 2 Questions	Completed	Rating
Processes	Design Authoring	1.1.0.1	Y	1.1.1.1.	91%	F	1.1.2.1.	47%	P
				1.1.1.2.	60%	M	1.1.2.2.	32%	P
				1.1.1.3.	20%	P	1.1.2.3.	5%	N
							1.2.2.4.	30%	P
							1.1.2.5.	36%	P
	Average result		Y		57%	M		30%	P
	3D Coordination	1.2.0.1	Y	1.2.1.1.	87%	F	1.2.2.1.	76%	M
				1.2.1.2.	99%	F	1.2.2.2.	85%	F
				1.2.1.3.	95%	F	1.2.2.3.	70%	M
	Average result		Y		93.67%	F		77.00%	M
	Design Reviews	1.3.0.1.	Y	1.3.1.1.	32%	P	1.3.2.1.	11%	N
				1.3.1.2.	57%	M	1.3.2.2.	20%	P
				1.3.1.3.	71%	M	1.3.2.3.	45%	P
				1.3.1.4.	69%	M	1.3.2.4.	38%	P
	Average result		Y		57.25%	M		28.50%	P
	BIM Project Management	1.4.0.1.	Y	1.4.1.1.	77%	M	1.4.2.1.	41%	P
				1.4.1.2.	91%	F	1.4.2.2.	56%	M
				1.4.1.3.	55%	M	1.4.2.3.	31%	P
	Average result		Y		71%	M		42.67%	P
Resources	Infrastructure	2.1.0.1.	Y	2.1.1.1.	98%	F	2.1.2.1.	52%	M
				2.1.1.2.	87%	F	2.1.2.2.	44%	P
				2.1.1.3.	85%	M	2.1.2.3.	25%	P
							2.1.2.4.	64%	M
							2.1.2.5.	31%	P
	Average result		Y		90%	F		43.20%	P
	Human Resources	2.2.0.2.	Y	2.2.1.1.	94%	F	2.2.2.1.	56%	M
				2.2.1.2.	69%	M	2.2.2.2.	59%	M
							2.2.2.3.	26%	P
	Average result		Y		81.50%	M		47%	P
	Rating guide:	N: Not reached – 0 to 15% P: Partially reached – 16%-50% M: Mostly reached – 51%-85% F: Fully reached – 85%-100%							

Figure 4.5 Sample hypothetical BIMUMM assessment

Each question is answered based on a completed percentage rate and N, P, M F system. The average result for the KPAs are calculated based on the average of completed rates and also N, P, M, F system.

4.5 Conclusion

The proposed model is based on construction client perspective. With this perspective, ‘minimum BIM qualification’ of construction project participants can be translated to ‘minimum capability to use BIM’ and this is practically what is wanted from a certification: ‘how well does this participant use BIM technology in a construction project?’. The need of construction clients for a practical BIM certification tool is considered for the proposed model. To develop the proposed BIMUMM, a maturity model from the software industry that is based on client perspective, namely Software Maintenance Maturity Model-S^{3M} (April, 2005), has been studied. The proposed BIMUMM is inspired from the S^{3M} architecture, which organizes activities in a hierarchical architecture from most general definitions to most specific practices. The hierarchial architecture, from level 1 (less specific) to most specific (level 4) respectively includes BIM “Domains”, “Key Process Areas (KPAs)”, “Roadmaps”, and “Practices”. Two domains of “BIM Precesses” and “BIM Recoureces” are at the first level of hierarchy. Each domain consists of several KPAs. The domain of “BIM Processes” includes the KPAs of: a) Design Authoring, b) 3D Coordination, c) Design Reviews, and d) BIM Project Management. The domain of “BIM Resources” includes the KPAs of: a) Infrastructure, and b) Human Resources. The KPAs of Design Authoring, 3D Coordination, and Design Reviews are specific BIM Uses and the other KPAs are considered as general BIM competencies. Each KPA contains a number of roadmaps that are defined at third level of hierarchy. Practices are defined at level 4 of hierarchy and within the roadmaps. The KPAs can be assessed against a maturity scale of six levels (levels 0-5). Reaching a maturity level requires the achievement of all the practices of that level. Each practice can be fully reached (F), Mostly reached (M), Partially reached (P), and Not reached (N). The proposed BIMUMM is in form of an assessment tool. A certified BIM maturity assessor (i.e. an independent assessment body) performs assessment of firms and issues the results and certificate. It is important to note that the proposed model of this research is developed from maturity levels 0 to 2, and the levels 3 to 5 is considered for future researchs. Also other BIM Uses can be considered for development of this model in future researchs.

Now that the main architecture of the proposed model has been presented in this chapter, the next chapter will describe the content of BIMUMM process domains, KPA's and practices for the three chosen BIM uses, and also KPA of 'BIM project management'.

CHAPTER 5

BIM PROCESSES DOMAIN

BIM domain of ‘Processes’ includes the required processes to use BIM and manage it. A process is a series of activites (tasks, steps, events, operations) that take an input, uses resources to add value to it and produce an output (product, service, or information) for a customer (Anjard, 1998; April, 2005). Therefore, BIM processes can also be defined as a series of activities that take an input and produce BIM outputs (BIM product, service, or information) by using resources. This chapter presents the detailed practices of the domain of BIM processes, which are defined within KPAs of ‘Design Authoring’, ‘3D Coordination’, ‘Design Review’, and ‘BIM Project Management’. As indicated in Figure 4.3, three most frequent BIM uses are selected as the first three KPAs of BIMUMM. The high usage of these BIM uses demonstrates their high degree of importance and their value for a construction project. Design Authoring is a first step towards BIM (CIC, 2011) and includes the process of creating BIM models. 3D Coordination is one of the main uses of BIM. There is a significant cost and time saving by identifying and addressing field conflicts in BIM 3D Coordination process. Design Review process, using BIM, provides an opportunity for the construction project stakeholders to vizualise a 3D model of the building, verify different design aspects and conformity with the requirements (CIC, 2011). Managing BIM in an organization is also an important issue and affects the achieved benefits of BIM. In this chapter and the following chapter 6, the BIM practices are presented. The practices are numbered based on the 4-digits codes, explained in Figure 5.1.

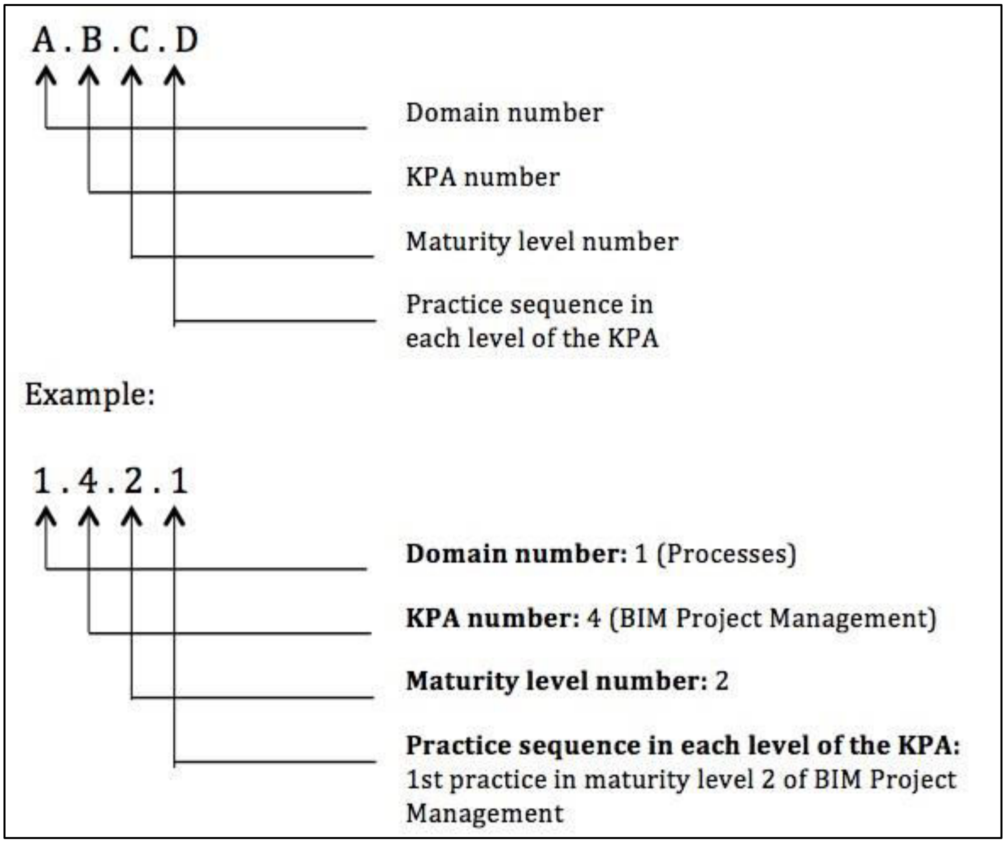


Figure 5.1 BIM Logic of numbering practices

5.1 Design Authoring KPA

In BIMUMM, the KPA of 'Design Authoring' in defined under BIM domain of 'Processes' and includes several Roadmaps as shown in Table 5.1.

Table 5.1 Design Authoring Roadmaps

BIM Domain	KPA	Roadmaps
Processes	Design Authoring	• Detailed process map of Design Review • Model content • Design Authoring required resources

During the design authoring process, the project team creates a 3D model of the building using authoring tools. In this BIM Use, the project team must define the detailed process of Design Authoring, the model content, and the required resources. The required practices for performing Design Authoring KPA are described in this section. Level zero refers to the lack of any support and activity for this process.

Therefore, **'Design Authoring' in Maturity Level 0**, can be described as follows:

Practice 1.1.0.1. The firm does not perform any BIM Design Authoring activity.
Explanation: In maturity level zero, the firm does not perform Design Authoring using BIM and there are no defined BIM processes and plans for Design Authoring. There is no software, hardware, or technological facilities to perform Design Authoring. Having software capable of reading or transferring 3D geometry to BIM software means level 0 of maturity. The firm does not have personnel with BIM skills and knowledge designated to perform Design Authoring. Design Authoring is a precondition for BIM: no Design Authoring means no BIM.
Question 1.1.0.1. Does your firm perform any BIM Design Authoring activity? Yes or No? (If Yes, continue to the next question)

5.1.1 Detailed Process Map of 'Design Authoring'

The Design Authoring process includes several activities during one or multiple phases of a project. In this process, the different project team members, i.e. architect, structure and MEP engineer, create their own models. The responsible party for each activity must be determined. They need to collaborate to create a model, which includes all information from the different disciplines. The collaboration among involved project members in the activities must be represented in a detailed process map (CIC, 2011; NIBS, 2007, Category of Roles or Disciplines; BIM quick scan, retrieved 2015, question 25).

In the Indiana University BIM Proficiency Matrix (2012), the information models of buildings are created during the design and construction phase of the project. The design model is shared with the contractor(s) to create the construction model of their own work and coordinate with the design model (Category G.2). Therefore, the model evolves as construction continues (Category G.3).

To identify activities, the relation and dependency of activities, responsible parties for the activities, and the required information and information exchanges and flow for a process, such as Design Authoring, (CIC, 2011, p. 20&21; NIBS, 2007, Category of Roles or Disciplines; Indiana University, 2012, Category G2), developing a process map is very helpful. According to Anjard (1998, p. 79), “a process map is a visual aid for picturing work processes which shows how inputs, outputs and tasks are linked. A process map prompts new thinking about how work is done. It highlights major steps taken to produce an output, who performs the steps, and where these (major) problems consistently occur”. Process maps is also useful for other BIM uses. The capability to develop a process map is defined at maturity level 3, which is out of scope of this research. Firstly, a firm has to formalize its BIM practice in procedures and then build BIM templates in maturity levels of 1 and 2, as prerequisites for a process map.

The required capabilities of firms to perform the Design Authoring process are presented from maturity level one to two as follows.

5.1.1.1 ‘Design Authoring’ Process Map Capability in Maturity Level 1

Practice 1.1.1.1. The firm defines procedures for BIM Design Authoring.
Explanation: At this level, a firm is replicating CAD procedures to develop BIM models. By CAD modeling, the firm is able to visualize a model and add geometric information in 2D and 3D, while BIM modeling provides automated design and different aspects of a model, more than just visualization and geometric information, can be added to a BIM model.

Therefore, process mapping is not used at this level that a firm is just managing BIM by adapting CAD procedures.

Question 1.1.1.1. Has your firm defined procedures for BIM Design Authoring? (Choose answer from: No, Partially, Mostly, Yes)

5.1.1.2 'Design Authoring' Process Map Capability in Maturity Level 2

Practice 1.1.2.1. The firm develops BIM defined procedures and templates for BIM Design Authoring.

Explanation: At this level, the firm defines BIM procedures and templates for BIM Design Authoing. However, these capabilities don't lead to preparing a process map at this level of maturity.

Question 1.1.2.1. Is your firm developing BIM defined procedures and templates for BIM Design Authoring (Choose answer from: No, Partially, Mostly, Yes)

5.1.2 Model Content

CIC (2011) developed the Information Exchange Worksheet "… to aid the project team to define the information required to implement each BIM Use with maximum efficiency". This worksheet uses a Model Element Breakdown to specify the elements of a building model. In order to model each component of a building, e.g. exterior walls, the responsible party and the level of detail can be identified. The level of detail also described with other names such as 'Level of Development' (DDC, 2012). NBIMS (2012) defines the level of detail as 'data richness'. Data richness "identifies the completeness of the Building Information Model from initially very few pieces of unrelated data to the point of it becoming valuable information and ultimately corporate knowledge about a facility" (NBIMS, 2012). According to DDC (2012) the Model Level of Development (LOD) describes the level of detail to which a model is developed and its minimum requirements. DDC developed LOD in alignment with the AIA- Exhibit 202 Document. These LOD are shown in appendix I. Other information for each BIM Use can be determined, such as time of information exchange, information receiver file format, and name of applications used and their version (CIC, 2012).

The Indiana University BIM Proficiency Matrix (Indiana University, 2012) specified some criteria for the maturity of a BIM model content as follows. The model must contain accurate geometry. Major building objects must be modeled (in Category A.1). The architectural, structural, and MEP models must be integrated within a single model (in Category B.2). The content of model elements must include their manufacturer specifications and information of the elements from the manufacturer, if applicable (in Categories E.2&H.3). A score from 0 to 1 is allocated to each category based on the reached level of maturity.

Another issue when considering the content of BIM models is facility data deliverables. Construction-Operations Building information exchange (COBie) proposes electronic format for providing operations, maintenance, and asset management information of a facility. Information regarding 'equipment' and 'space', such as equipment list, warranties, manufacturer, model, serial number, etc. are included in COBie. While COBie files are available in different formats, such as the STEP Physical File Format (ISO 10303 Part 21) which conforms to the Industry Foundation Class (IFC) (ISO 16739), a translation of data can be produced as spreadsheets. Since 2012, COBie has been part of US National BIM Standard (East, 2014). A sample COBie spreadsheet is shown in Figure 5.2.

The UK government intended to require collaborative 3D BIM in its projects by 2016 and use the structured data exchange format in COBie (Government Construction Strategy, 2012). Therefore, COBie can be considered in maturity levels higher than two in this research, in collaborative BIM, which is out of scope of this thesis.

	A	B	C	D	E	F	G	H	I
1	Product	Product Type	Room Number	Manufacturer	Supplier	Critical	Installed Model Number	Installed Serial Number	Installed On
2	Fan-CentrifugalRoofExhauster-Downblast-RF01	Fan-CentrifugalRoofExhauster-Downblast	Roof-2	sales@greenheck.com	Email	Moderate	GB101-HP	DHRF001	26-Apr-2012
3	Fan-CentrifugalRoofExhauster-Upblast-SEF01	Fan-CentrifugalRoofExhauster-Upblast	Roof-2	sales@greenheck.com	Email	Moderate	S-Cube-161HP	SJSSEF001	26-Apr-2012
4	Fan-CeilingCabinet-EF2	Fan-CeilingCabinet	108	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO0	26-Apr-2012
5	Fan-CeilingCabinet-EF3	Fan-CeilingCabinet	204	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO1	26-Apr-2012
6	Fan-CeilingCabinet-EF4	Fan-CeilingCabinet	206	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO2	26-Apr-2012
7	Fan-CeilingCabinet-EF5	Fan-CeilingCabinet	208	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO3	26-Apr-2012
8	Fan-CeilingCabinet-EF6	Fan-CeilingCabinet	210	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO4	26-Apr-2012
9	Fan-CeilingCabinet-EF7	Fan-CeilingCabinet	212	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO5	26-Apr-2012
10	Fan-CeilingCabinet-EF8	Fan-CeilingCabinet	214	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO6	26-Apr-2012
11	Fan-CeilingCabinet-EF9	Fan-CeilingCabinet	216	sales@greenheck.com	Email	Moderate	SP-B50	JU8KLO7	26-Apr-2012
12	Fan-InlineCeilingCabinet-EF1	Fan-InlineCeilingCabinet	102	sales@greenheck.com	Email	Moderate	CSP-A190	AK654	26-Apr-2012
13	Fan-InlineCentrifugal-KEF2	Fan-InlineCentrifugal	112	sales@vikingrange.com	Email	Moderate	VINV600	AKSA45	26-Apr-2012
14	Fan-ReliefAir-RAF1	Fan-ReliefAir	Roof-1	sales@greenheck.com	Email	Moderate	FGR	LSODS90	26-Apr-2012

Figure 5.2 Sample typical COBie spreadsheet of equipment
Taken from NIBS (2015)

5.1.2.1 Model Content' Capability in Maturity Level 1

Practice 1.1.1.2. The firm is able to produce a library of simple BIM families (Indiana University, 2012, Category A1; NIBS, 2012).

Explanation: The firm starts using BIM for 3D visualization of the building (BIM quick scan, 2012). Data richness of BIM models is basic (NIBS, 2012). The firm is able to produce simple library families of BIM elements.

Question 1.1.1.2. Is your firm able to produce a library of simple BIM families? (Choose answer from: No, Partially, Mostly, Yes)

5.1.2.2 'Model Content' Capability in Maturity Level 2

Practice 1.1.2.2. The firm is able to produce a library of complex BIM families (Indiana University, 2012, Category A1; NIBS, 2012).

Explanation: The firm is capable of using BIM software to produce a library of complex BIM families. Data richness is enhanced (NIBS, 2012) and modeling contains more complex objects.

Question 1.1.2.2. Is your firm able to produce a library of complex BIM families? (Choose answer from: No, Partially, Mostly, Yes)

Practice 1.1.2.3. The firm manages BIM Design Authoring process using a formalized definition and control of LOD (CIC, 2012, p. 36; NIBS, 2012, Category Data Richness levels 3&4; Indiana University, 2012, Category A1; Quick scan tool, retrieved 2015, question 32; Eastman et al., 2011, p. 234).

Explanation: At this level, the firm manages creating BIM models in the process of Design Authoring, using a formalized definition and control of LOD. Therefore, LOD-related issues are avoided by defined and controlled LOD.

Question 1.1.2.3. Is your firm managing BIM Design Authoring process using a formalized definition and control of LOD? (Choose answer from: No, Partially, Mostly, Yes)

5.1.3 'Design Authoring' Required Resources

Design Authoring tools, including 3D design software such as Revit Architecture, Revit Structure, Tekla Structure, Revit MEP, etc., are required to create a BIM model. The design applications specific for each discipline must be available on suitable hardware equipment, like a PC/laptop, and proper information transfer network is necessary to enable design personnel to design the architectural, structural, and MEP models. Resources are not just limited to technology aspects. The human resource is another factor. Knowledge, experience, and skills of the personnel using the technologies and their collaboration is required to succeed in the BIM execution.

5.1.3.1 'Design Authoring' Resources in Maturity Level 1

Practice 1.1.1.3. The firm has recognized Design Authoring software in their discipline(s) (i.e. Revit, Tekla Structure, Magicad) with powerful enough hardware and qualified human resources which enables creating BIM models (CIC, 2011, P. 60; BIM quick scan, 2012, question 41&44, Succar, 2010a, category software level a).

Explanation: The firm has Design Authoring software in their discipline with powerful enough hardware and qualified human resources for creating BIM models. "Design authoring tools are a first step towards BIM and the key is connecting the 3D model with a powerful database of properties, quantities, means and methods, costs and schedules" (CIC, 2011, p. 60). At this maturity level, these applications are not used properly due to human resource issues such as lack of knowledge, experience, skills of personnel, and collaboration issues, etc.

Question 1.1.1.3. Does your firm have recognized Design Authoring software (i.e. Revit, Tekla Structure, Magicad) with powerful enough hardware and qualified human resources that enables creating BIM models? (Choose answer from: No, Partially, Mostly, Yes)

5.1.3.2 'Design Authoring' Resources in Maturity Level 2

Practice 1.1.2.4. The firm has recognized Design Authoring software (i.e. Revit, Tekla Structure, Magicad) with powerful enough hardware and qualified human resources and can manage exchange of information between different BIM software for coordination or analysis and integratation of BIM models (Indiana University, 2012, category B2; BIM quick scan, retrieved 2015, question 41&44, Succar, 2010a, category software level b).

Explanation: The firm has recognized Design Authoring software with powerful enough hardware and qualified human resources for creating a 3D model in its discipline and can manage exchange of information between different BIM software for coordination or analysis. For management of information exchange, the firm may have an interoperability matrix identifying the level of interoperability between various BIM software. The firm is capable of delivering an integrated model and is ready to add more information, other than 3D visualization, to model elements.

Question 1.1.2.4. Does your firm have recognized Design Authoring software (i.e. Revit, Tekla Structure, Magicad), with powerful enough hardware and qualified human resources and can manage exchange of information between different BIM software for coordination or analysis and integration of BIM models? (Choose answer from: No, Partially, Mostly, Yes)

Practice 1.1.2.5. The firm is able to extract BIM data to be used for analysis (i.e. cost, energy simulation, structure, etc)

Explanation: The ability to extract BIM data from the models for different analysis, such as cost, energy, simulation, structure, etc, is a higher level than just design authoring. In this level, the firm can extract the required data for different analysis.

Question 1.1.2.5. Is your firm able to extract BIM data from the models to be used for analysis or other tasks in non-BIM software (i.e. cost, energy simulation, structure, etc)? (Choose answer from: No, Partially, Mostly, Yes)

5.2 3D Coordination KPA

In BIMUMM, the KPA of '3D Coordination' is defined under BIM domain of 'Processes' and includes several Roadmaps as shown in Table 5.2.

Table 5.2 3D Coordination Roadmaps

BIM Domain	**KPA**	**Roadmaps**
Processes	3D Coordination	• Detailed process map of 3D Coordination • Defining 3D Coordination information requirements • Performing collision detection and solving collision problems

CIC (2011) describes BIM Use of '3D Coordination' as "a process in which Clash Detection software is used during the coordination process to determine field conflicts by comparing 3D models of building systems. The goal of clash detection is to eliminate the major system conflicts prior to installation". The design team must check collision against architectural, structural and MEP models of a project. The collision reports must be prepared, and then the project team or responsible members must review the collision report and address the issues in the models (Indiana University, 2012, category A.3). This process includes several activities, which must be mapped with their relationships in a detailed process map. The capabilities in a '3D Coordination' process are defined under four roadmaps of 'Process map', 'Information requirements', 'Creating, transferring, and compiling information', and 'Collision detection and solving'. These capabilities are explained as follows.

In higher levels of maturity (higher than level 2) it is expected that more capabilities be reached in 3D Coordination, such as Walk-through and 4D interference checks. These capabilities are out of scope for this thesis.

For maturity level zero, no activity and resource is considered.

Therefore, **'3D Coordination' in Maturity Level 0,** can be described as follows:

Practice. 1.2.0.1. The firm does not perform any 3D Coordination activity using BIM.
Explanation: The firm does not perform 3D coordination using BIM and there are no defined BIM processes and plans for 3D coordination. There is no software, hardware, and technological facilities to perform 3D BIM coordination. The firm can have BIM software, hardware, and technological facilities for other BIM Uses, such as Design Authoring, but is not using them for 3D coordination. The firm does not have personnel with BIM skills and knowledge designated to perform 3D coordination.
Question 1.2.0.1. Does your firm perform any 3D Coordination activity using BIM? Yes or No? (If Yes, continue to the next question)

5.2.1 Detailed Process Map of '3D Coordination'

The organization responsible for performing '3D Coordination' must be able to develop a detailed process map of this BIM Use to reach high levels of maturity. The detailed map must contain all necessary activities and connect them properly. The responsible party for each activity must be determined. According to CIC (2011), Eastman et al. (2011), and Indiana University (2012), the main activities of 3D Coordination can be concluded as defining information requirements, performing collision detection and solving collision problems.

To identify activities, the relation and dependency of activities, responsible parties for the activities, and the required information and information exchanges and flow for a process, such as Design Authoring, (CIC, 2011, p. 20&21; NIBS, 2007, Category of Roles or Disciplines; Indiana University, 2012, Category G2), developing a process map is very helpful.

The capability to develop a process map is defined at maturity level 3, which is out of scope of this research. Firstly, a firm has to formalize its BIM practice in procedures and then build BIM templates in maturity levels of 1 and 2, as prerequisites for a process map. The required capabilities and questions are as follows.

5.2.1.1 '3D Coordination' Process Map Capability for Maturity Level 1

Practice 1.2.1.1. The firm performs individual ad hoc procedures for clash detection.
Explanation: At this level of maturity, the firm is not performing clash detection as a defined process. In individual ad hoc procedures for clash detection, the firm doesn't use process map.
Question 1.2.1.1. Does your firm perform individual ad hoc procedures for clash detection? (Choose answer from: No, Partially, Mostly, Yes)

5.2.1.2 '3D Coordination' Process Map Capability for Maturity Level 2

Practice 1.2.2.1. The firm follows defined procedures for clash detection.

Explanation: At this level, to perform 3D Coordination in a project, the responsible firm(s) needs to define clash detection procedures. However, defining clash detection procedures doesn't lead to development of a process map.

Question 1.2.2.1. Does your firm follow defined procedures for clash detection? (Choose answer from: No, Partially, Mostly, Yes)

5.2.2 Defining '3D Coordination' Information Requirements

Clash check can be done between specified building systems, i.e. mechanical and structural systems, because model components belong to a specific type of system (Eastman et al., 2011). Clash detection can also be done within one discipline. For example, "a clash between surfaces could be a wall abutting a wall or a pipe running through a wall" (Eastman et al., 2011). Therefore, 3D Coordination information requirements define intended building systems for conflict detection, including structural, mechanical, engineering, plumbing systems, and civil systems such as storm water systems, buried electrical systems (e.g. duct banks), rails, sewer systems, etc. After defining the required building systems' model, the level of detail of models must be defined for each model. A contractor can also benefit from clash detection: "… the contractor must ensure that the building is modeled with an appropriate level of detail. It must have sufficient details for piping, ducts, structural steel (primary and secondary members) and attachments, and other components, so that clashes can be accurately detected" (Eastman et al., 2011, p. 273). To define LOD at the beginning of a project, the clash detection information requirements must be considered for future 3D coordination during the project. Clash check can be done in different LODs, and the required LODs for clash detection depends on the needs of the project and can be indicated.

5.2.2.1 '3D Coordination' Information Requirements Capability in Maturity Level 1

Practice 1.2.1.2. The firm carries out a clash check of BIM models within its discipline(s) (Eastman et al, 2011, p. 273; Indiana University, 2012, category A.3).

Explanation: At this maturity level, the firm initiates irregular clash check of BIM models, within the firm's discipline. At this level it is expected that the firm be capable of conducting a clash check in its discipline (not multi-disciplines). To reach this level of maturity, conducting clash checks even in an irregular manner is acceptable.

Question 1.2.1.2. Is your firm capable of carrying out a clash check of BIM models within your firm discipline(s)? (Choose answer from: No, Partially, Mostly, Yes)

5.2.2.2 '3D Coordination' Information Requirements Capability in Maturity Level 2

Practice 1.2.2.2. The firm carries out a multi-discipline clash check of BIM models (Eastman et al, 2011, p. 273; Indiana University, 2012, category B.2).

Explanation: At this maturity level, the firm carries out a multi-discipline clash check of architectural, structural, and mechanical, engineering and plumbing (MEP) building models, against each other and within the disciplines. This process is part of the firm's procedures.

Question 1.2.2.2. Does your firm carry out regular multi-discipline clash checks of BIM models? (Choose answer from: No, Partially, Mostly, Yes)

5.2.3 Performing Collision Detection and Solving Collision Problems

The location and schedule for 3D Coordination meetings must be defined. In the meetings, the conflict problems must be addressed. Therefore, a protocol to address collisions is required before beginning the coordination process (CIC, 2011). Clashes can be categorized in two groups. A group of them, which are small errors, can be defined as minor clashes. Minor clashes can be ignored in the design phase and can be addressed during construction, on the site (Amiri, 2012). However, major clashes must be identified and addressed during the 3D Coordination meetings. Figure 5.3 shows a clash detection picture from Autodesk Navisworks Manage.

3D coordination can benefit from Cloud Computing. The National Institute of Standards and Technology (NIST) defines Cloud Computing as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell and Grance 2011). Autodesk® presented the ‘BIM 360 Glue™’ application to “coordinate construction and design in real-time on the cloud” (Autodesk [4]).

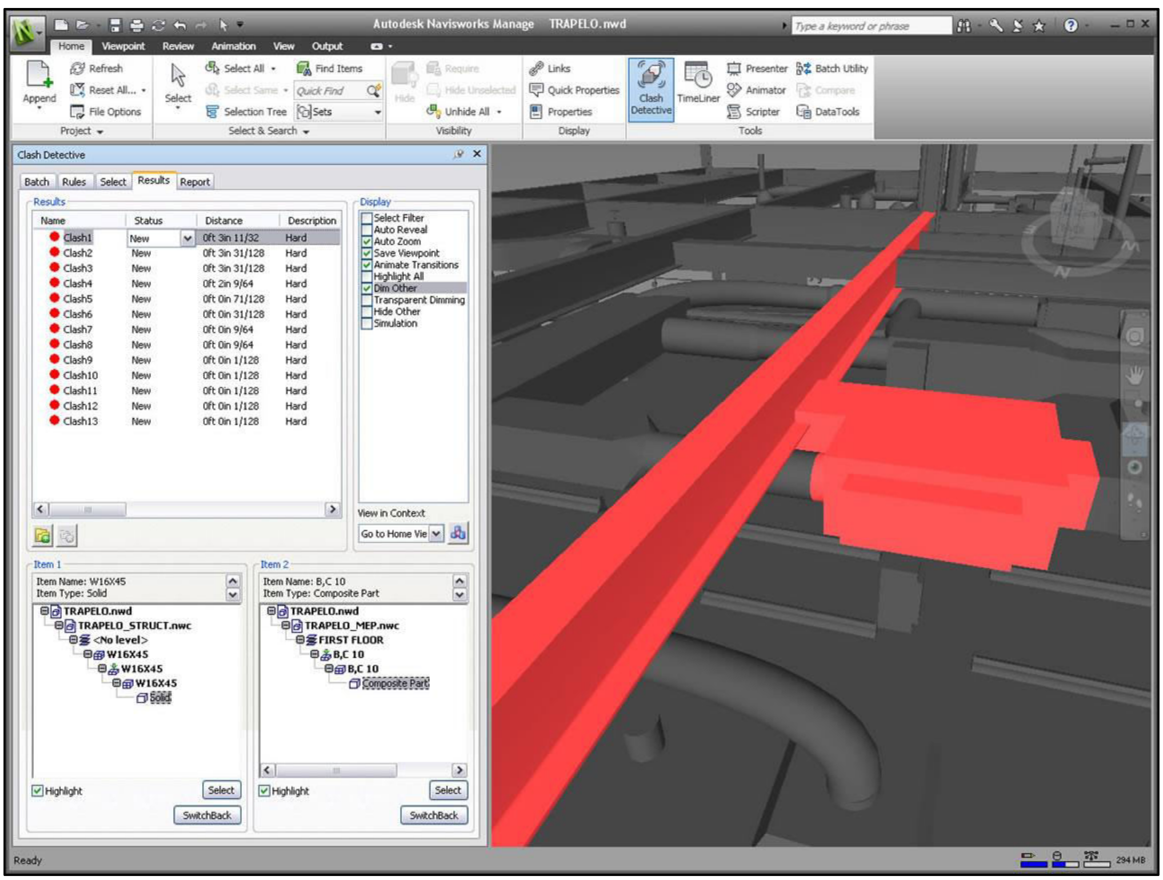


Figure 5.3 Clash and interference management in Autodesk Navisworks Manage
Taken from (Autodesk [2])

For this study, cloud Computing for clash detection is currently considered for BIM maturity levels of higher than 2, which is out of the scope of this research.

5.2.3.1 Clash detection and solving capability in Maturity level 1

Practice 1.2.1.3. The firm has assigned the indivisual(s) to preform clash detection and solving; and in required cases, participate in regular clash check meetings, with determined schedule and location, in order to review, discuss and address the clash problems, using their BIM authoring software to detect clashes (Indiana University, 2012, A.3; Succar, 2010a, p. 90).

Explanation: The organization assigns at least one competent person to preform clash detection and solving; and in required cases, to participate in clash check meetings to address the problems. In each meeting, the firm's representative(s) and the other project members involved in a clash check, review the collision report and discuss how to address detected clashes, using their BIM authoring software to detect clashes.

Question 1.2.1.3. Has your firm assigned the indivisual(s) to preform clash detection and solving; and in required cases, participate in regular clash check meetings, with determined schedule and location, in order to review, discuss and address the clash problems, using their BIM authoring software to detect clashes? (Choose answer from: No, Partially, Mostly, Yes)

5.2.3.2 Clash detection and solving capability in Maturity level 2

Practice 1.2.2.3. The firm defines a protocol to address the detected clashes, using specialized software for clash detection, and has a resource dedicated to clean the models before conducting clash detection sessions (CIC, 2011, p. 86).

Explanation: The firm establishes a protocol to address the detected clashes (CIC, 2011). This protocol includes instructions to clarify how to resolve the clashes and how to define clashes as minor and major (Amiri, 2012). At this level, the firm has a resource dedicated to clean the models before conducting clash detection sessions.

Question 1.2.2.3. Does your firm define a protocol to address the detected clashes, using specialized software for clash detection, and has a resource dedicated to clean the models before conducting clash detection sessions? (Choose answer from: No, Partially, Mostly, Yes)

5.3 Design Reviews KPA

In BIMUMM, the KPA of ‘Design Reviews’ is defined under BIM domain of ‘Processes’ and includes several Roadmaps as shown in Table 5.3.

Table 5.3 Design Reviews Roadmaps

BIM Domain	KPA	Roadmaps
Processes	Design Reviews	• Detailed process map of Design Reviews • Virtual model review • Constructability review • Operation and Maintenance (O&M) review

According to CIC (2011) ‘Design Review’ BIM Use is “a process in which stakeholders view a 3D model and provide their feedback to validate multiple design aspects. These aspects include evaluating conformity with the program, previewing space aesthetics and layout in a virtual environment, and setting criteria such as layout, sightlines, lighting, security, ergonomics, acoustics, textures and colors, etc.”. Design review activities can be defined in three categories, including virtual model review, Operation and Maintenance (O&M) review, and constructability review (CIC, 2011).

To identify activities, the relation and dependency of activities, responsible parties for the activities, and the required information and information exchanges and flow for a process, such as Design Authoring, (CIC, 2011, p. 20&21; NIBS, 2007, Category of Roles or Disciplines; Indiana University, 2012, Category G2), developing a process map is very helpful. The capability to develop a process map is defined at maturity level 3, which is out of scope of this research. Firstly, a firm has to formalize its BIM practice in procedures and then build BIM templates in maturity levels of 1 and 2, as prerequisites for a process map.

In maturity level 0 of design review, no resource and activity is allocated to this process:

Therefore, **'Design Review' in Maturity Level 0,** can be described as follows:

Practice 1.3.0.1. The firm does not perform any Design Review activity using BIM.
Explanation: The firm does not perform Design Review using BIM and there are no defined BIM processes and plans for Design Review. There is no software, hardware, and technological facilities to perform Design Review. The firm does not have personnel with BIM skills and knowledge designated to perform Design Review.
Question 1.3.0.1. Does your firm perform any Design Review activity using BIM? Yes or No? (If Yes, continue to the next question)

5.3.1 Detailed Process Map of 'Design Review'

All the activities of a Design Review process for a project must be mapped in detail. The order and relation among activities, responsible parties, and information exchange of activities must be defined in the detailed process map (CIC, 2011).

5.3.1.1 'Design Review' Process Map Capability for Maturity Level 1

Practice 1.3.1.1. The firm defines procedures to review BIM models.
Explanation: At this level, a firm is able to use CAD procedures to review BIM models. The firm is able to review model visualization and geometric information in 2D and 3D, while in BIM procedures other properties of models are also reviewed. Therefore, process mapping is not used at this level that a firm is just managing BIM by adapting CAD procedures.
Question 1.3.1.1. Has your firm defined procedures for BIM Design Review?

5.3.1.2 'Design Review' Process Map Capability for Maturity Level 2

Practice 1.3.2.1. The firm defines BIM procedures and templates for Design Review.
Explanation: At this level, the firm defines BIM procedures and templates for Design Review process. However, these capabilities don't lead to preparing a process map at this level of maturity.
Question 1.3.2.1. Is your firm defining BIM procedures and templates for Design Review (Choose answer from: No, Partially, Mostly, Yes)

5.3.2 Virtual Model Review

The architect conducts a review of a virtual model of a building to enable the user(s) to imagine what the final building looks like. The virtual model can be an integrated model of all disciplines. The user and other stakeholders can provide feedback on various design aspects, such as spaces, colors, lighting, texture, etc. (CIC, 2011). Based on the feedback, the required changes can be performed on the model. This review applies only to architect.

5.3.2.1 Virtual Model Review Capability in Maturity Level 1

Practice 1.3.1.2. The architect conducts a design review of a multi-disciplines integrated virtual model of a building to validate certain design aspects (CIC, 2011, p. 66).
Explanation: The architect is capable of providing an integrated multi-discipline 3D model of a building for design review by project stakeholders to validate certain design aspects (CIC, 2011), i.e. configuration of the mechanical room.
Question 1.3.1.2. Does your architectural firm conduct design reviews of an integrated multi-disciplines virtual model of a building to validate certain design aspects? (Choose answer from: No, Partially, Mostly, Yes)

5.3.2.2 Virtual Model Review Capability in Maturity Level 2

Practice 1.3.2.2. The architect conducts a design review of an integrated multi-discipline virtual model of a building to verify compliance to program (CIC, 2011, p. 66) or code requirements.

Explanation: The architect is capable of providing an integrated multi-discipline 3D model of a building for design review by project stakeholders to verify compliance to program (CIC, 2011, p. 66) or code requirements.

Question 1.3.2.2. Does your architectural firm conduct design reviews of an integrated multi-discipline virtual model of a building to verify compliance to program or code requirements? (Choose answer from: No, Partially, Mostly, Yes)

5.3.3 Constructability review

Depending on the project delivery method, a contractor (or a construction manager) can be responsible for performing the Constructability Review (CIC, 2011) optimally when 90-100 percent of design is reached which is when the scope of the design work is finalized and all drawing details, notes and specifications have been incorporated and gathered (Pettee, retrieved January 2015). Pettee S. R. (retrieved January 2015) defined a Constructability Review as "an independent and structured review of construction bid documents by construction professionals to make certain that the work requirements are clear, the documents are coordinated, and that they assist the contractor in bidding, construction and project administration to result in reduced impacts to the project".

5.3.3.1 Constructability Review Capability in Maturity Level 1

Practice 1.3.1.3. The firm performs individual ad hoc constructability review.

Explanation: The firm is able to perform individual ad hoc constructability review. However, the process is not on a regular based and in defined BIM procedures.

Question 1.3.1.3. Does your firm perform individual ad hoc constructability review? (Choose answer from: No, Partially, Mostly, Yes)

5.3.3.2 Constructability Review Capability in Maturity Level 2

Practice 1.3.2.4. The firm performs a Constructability Review by using an integrated multi-disciplinary BIM model (CIC, 2011, p. 66; Pettee, retrieved 2015).

Explanation: The firm benefits from a BIM model, which is integrated from models of all disciplines including architecture, structural and MEP, to perform a Constructability Review in the final stages of design (Pettee, retrieved 2015).

Question 1.3.2.4. Does your firm perform a Constructability Review using an integrated multi-disciplinary BIM model? (Choose answer from: No, Partially, Mostly, Yes)

5.3.4 Operation and Maintenance (O&M) Review

All disciplines compile information of their models for the facility manager to perform an Operation and Maintenance (O&M) review (CIC, 2011). In order to better operate and maintain a facility during its lifecycle, the facility manager needs to review the building design and provide feedback when needed. Eastman et al. (2011) emphasize the role of owner in O&M review as follows: "A building information model enables virtual coordination of a building's infrastructure across all disciplines. The owner of a facility can include its own representatives from its maintenance and operations staff to provide input and review of the model. Rework due to design flaws can potentially be avoided". However, O&M Review is considered as an optional requirement for the construction clients and they don't usually require it.

5.3.4.1 Operation and Management (O&M) Review Capability in Maturity Level 1

Practice 1.3.1.4. The firm has experience in conducting Operation and Management (O&M) Review (CIC, 2011, p. 66).

Explanation: The firm has experience to conduct Operation and Management (O&M) Review. Although the firm has been part of O&M review process, it has not provided appropriate views and data from an integrated multi-disciplines BIM model for this goal.
Question 1.3.1.4. Does your firm have experience in conducting Operation and Management (O&M) Review? (Choose answer from: No, Partially, Mostly, Yes).

5.3.4.2 Operation and Management (O&M) Review Capability in Maturity Level 2

Practice 1.3.2.4. The firm can provide appropriate views and data from an integrated multi-discipline 3D model for the Operation and Management (O&M) Review, with minimum LOD 300, to the facility owner or its representatives (CIC, 2011, p. 66).
Explanation: BIM models from all disciplines, namely architectural, structural, and MEP, are integrated in a single model to be used for providing appropriate views and data for Operation and Management (O&M) Review to the facility owner or its representatives.
Question 1.3.2.4. Can your firm provide appropriate views and data from an integrated multi-discipline 3D model for the Operation and Management (O&M) Review, with minimum LOD 300, to the facility owner or its representatives? (Choose answer from: No, Partially, Mostly, Yes)

5.4 BIM Project Management KPA

In BIMUMM, the KPA of ‘BIM Project Management’ is defined under BIM domain of ‘Processes’ and includes several Roadmaps as shown in Table 5.4.

Table 5.4 BIM project management Roadmaps

BIM Domain	**KPA**	**Roadmaps**
Processes	BIM project management	• BIM project execution planning • BIM collaboration • BIM quality control

To manage BIM in a project, the participating firms must have several capabilities. They need to contribute to the development of the project BIM execution plan. In addition, using BIM in a construction project is a collaborative process. The project participants must be able to use BIM in a collaborative environment. Finally, the firms involved in the project must be able to control the quality of their BIM products to ensure the expected quality is achieved.

Establishing documented processes, procedures, workflow, and management of BIM content is part of the essential responsibilities of a BIM manager (Joseph, 2011). Kymmell (2008) defines a BIM manager as “a person who coordinates the team that is responsible for the production and analysis of the BIM”. Joseph (2011) defined the full roles and responsibilities of a BIM manager, as shown in appendix II. Also, more information regarding BIM managers, from Kymmell (2008), can be found in appendix IV.

Lack of a BIM manager in a firm is equivalent to level zero of the BIM management process.

Therefore, **BIM Project Management in Maturity Level 0,** can be described as follows:

Practice 1.4.0.1. The firm does not have any BIM managers.
Explanation: A BIM manager is required to define and conduct BIM management activities in the firm.
Question 1.4.0.1. Does your firm have any BIM managers? Yes or No? (If Yes, continue to the next question)

The BIM project management capabilities are explained as follows.

5.4.1 BIM project execution planning

The BIM execution plan is a document developed by the project team in the early stages of a project and can be monitored, updated, and revised throughout the project. Different content is expected to be included in a BIM execution plan. For example, according to CIC 2011 “the plan should define the scope of BIM implementation on the project, identify the process flow for BIM tasks, define the information exchanges between parties, and describe the required project and company infrastructure needed to support the implementation”. The BIM execution plan of Indiana University (2012) defines “… roles and responsibilities of each party, the detail and scope of information to be shared, relevant business processes and supporting software”. The role of the BIM manager is essential for the development of the BIM execution plan and must be considered in the first level of maturity in the process of BIM project management.

5.4.1.1 BIM Project Management in Maturity Level 1

Practice 1.4.1.1. The firm has a BIM manager who works at least in a part-time basis (CIC, 2011).

Explanation: In this maturity level, the firm has assigned a BIM manager, who works at least in a part-time basis, to define and conduct activities related to BIM management in the firm and for the project. However, the firm does not have any experience in assisting the project team with the development of a BIM project execution plan (CIC, 2012, p. 58). The BIM manager is capable of creating a BIM execution plan template for the firm.

Question 1.4.1.1. Does your firm have a BIM manager who works at least in a part-time basis? (Choose answer from: No, Partially, Mostly, Yes) (Remark: the answer can be partially or mostly when your BIM manager is doing only some of the tasks of a BIM manager or somebody is doing only some tasks of a BIM manager in your firm)

5.4.1.2 BIM Project Execution Planning Capability in Maturity Level 2

Practice 1.4.2.1 The firm has actively contributed in a BIM project execution planning process with other firms involved in project (CIC, 2011; Indiana University, 2012, p. 5).

Explanation: Project participants usually develop the BIM project execution plan in the early stages of the project to detail how information will be produced and shared between the firms. The firm has assigned a full-time BIM manager who is experienced in assisting the project team with the development of a BIM project execution plan.

Question 1.4.2.1 Has your firm ever actively contributed in a BIM project execution planning process with other firms involved in the project? (Choose answer from: No, Partially, Mostly, Yes)

5.4.2 BIM collaboration

Collaboration among project stakeholders is an important issue in BIM implementation in a project. Different project stakeholders, such as the owner, facility manager, engineer, architect, general contractor, subcontractor, and fabricator, benefit from BIM (Figure 5.4).

Prior to the beginning of a project, the project team must know the collaboration strategy, details on collaboration activities supported by BIM, the schedule for information exchange between parties, interactive workspace, and electronic communication procedures (CIC, 2011).

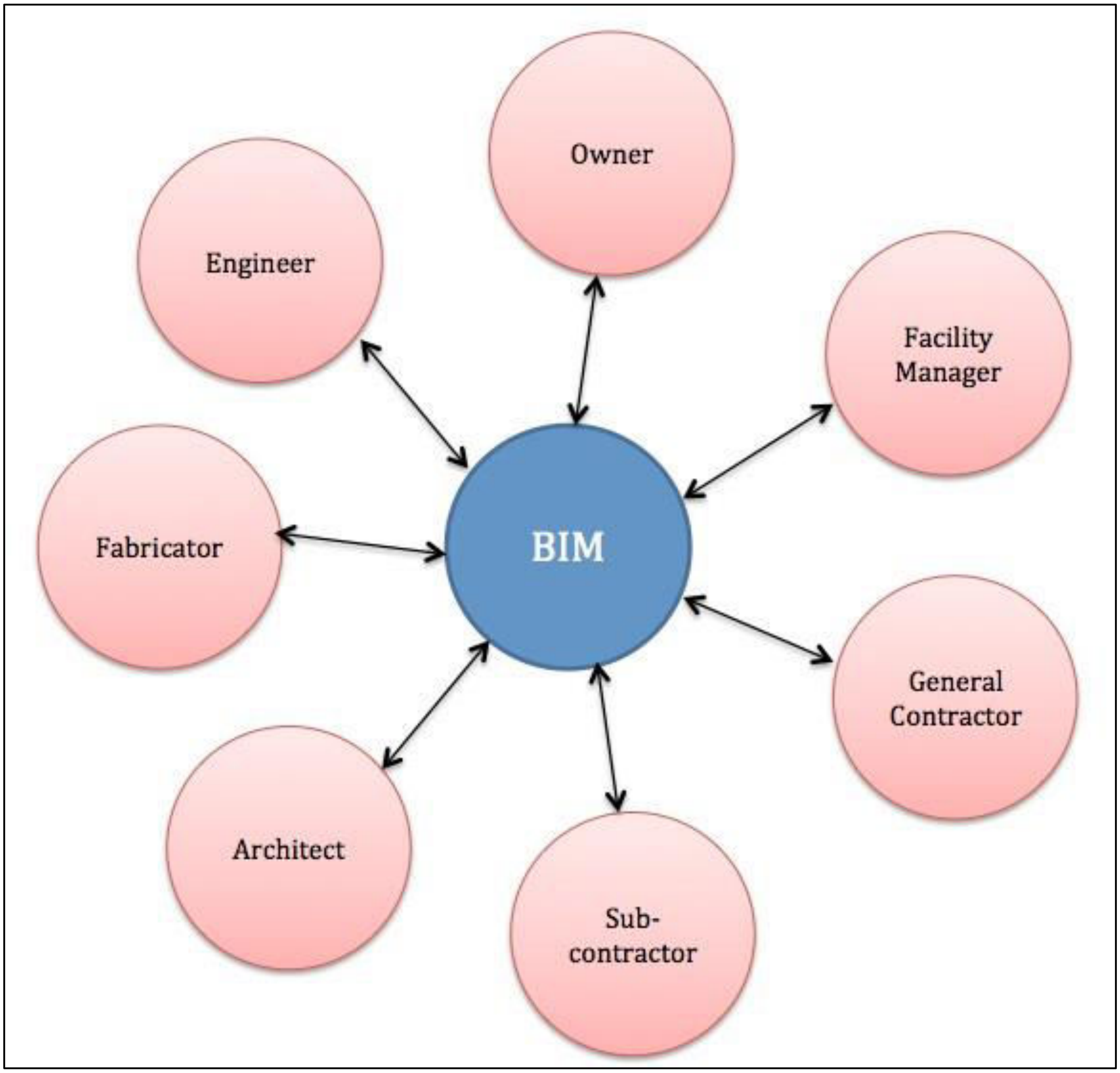


Figure 5.4 BIM beneficiaries of a project
Adapted from Eastman et al. (2011)

5.4.2.1 BIM Collaboration Capability in Maturity Level 1

Practice 1.4.1.2. The firm has experience of collaboration with other firms to deliver BIM services/products (CIC, 2012, p.58; BIM quick scan, question 26) and accepts to share BIM model with other disciplines.

Explanation: The experience of working in a collaborative environment for using BIM is a factor for ensuring the BIM collaboration capability of a firm (CIC, 2012). The firm should accept to share BIM model with other disciplines, at this level.

Question 1.4.1.2. Does your firm have experience of collaboration with other firms to deliver BIM services/products and accept to share BIM model with other disciplines? (Choose answer from: No, Partially, Mostly, Yes)

5.4.2.2 BIM Collaboration Capability in Maturity Level 2

Practice 1.4.2.2. The firm has experience of collaboration with other firms to deliver BIM services/products, and defines its BIM collaboration process for each project according to the structure of project, and encourages model sharing and synchronization (CIC, 2012, p.58; BIM quick scan, question 26).

Explanation: In addition to experience of BIM collaboration in previous projects, the firm is "willing to share information with other team members" (CIC, 2012, p.58) and describe/write down the information flow between itself and its project partners (BIM quick scan, question 26). The firm has a higher level of readiness for BIM collaboration at this level, in comparison with maturity level 1.

Question 1.4.2.2. Does your firm have experience of collaboration with other firms to deliver BIM services/products, and define its BIM collaboration process for each project according to the structure of project, and encourage model sharing and synchronization? (Choose answer from: No, Partially, Mostly, Yes)

5.4.3 BIM quality control

The project team must control the quality of their BIM deliverables, i.e. their design, dataset and model properties. CIC (2011) introduced the following quality control checks:

- Visual Check: by using navigation software they must make sure that the design intent is followed and no unintended model component exists;

- Interference Check: detect problems caused by the clash of two building model components by using 'Conflict Detection software';
- Standards Check: ensure conformity of the model with standards agreed upon by the team;
- Element Validation: check the dataset to be sure that there are no undefined or incorrectly defined elements.

5.4.3.1 Quality Control Capability in Maturity Level 1

Practice 1.4.1.3. The firm performs 'Visual Check' for BIM quality control purposes and in order to avoid unintended model components (CIC, 2011, p. 31&32; BIM quick scan, questions 7&8).
Explanation: By a visual check of BIM models, the firm makes sure that the design intent is followed and there is no unintended model component (CIC, 2011). Visual check is the first basic step and the simplest capability to control the quality of BIM products.
Question 1.4.1.3. Does your firm perform a 'Visual Check' for BIM quality control purposes and in order to avoid unintended model components? (Choose answer from: No, Partially, Mostly, Yes)

5.4.3.2 Quality Control Capability in Maturity Level 2

Practice 1.4.2.3. The firm performs 'Element Validation' for BIM quality control purposes and in order to avoid undefined or incorrectly defined elements by using software, such as Solibri Model Checker (CIC, 2011, p. 31&32; BIM quick scan, questions 7&8).
Explanation: In the building information modeling process, there is a possibility to have some model elements that are undefined or are incorrectly defined. To avoid these errors, the firm must validate elements after modeling completion. This is part of quality control of BIM models (CIC, 2011). To perform quality control, there is a software such as Solibri Model Checker that performs tasks such as (Solibri, retrieved on 2015): a) Deficiency Detection: "search for components and materials missing from the model"; b) Verify Matching Elements in Architectural & Structural Designs: "locate flaws and exceptions in models

made by different design teams. Avoid expensive rework by knowing both models match"; etc. It is expected that a firm be capable of validating BIM model elements, as a requirement to reach maturity level 2.

Question 1.4.2.3. Does your firm perform 'Element Validation' for BIM quality control purposes and in order to avoid undefined or incorrectly defined elements? (Choose answer from: No, Partially, Mostly, Yes)

5.5 Conclusion

As indicated in figure 5.5, BIM domain of 'Processes' includes four KPAs, a total of 13 'Roadmaps', and 32 practices/questions in 3 maturity levels of 0, 1, and 2. Each Roadmap is specific to one or several disciplines as indicated. In the proposed model, the KPA of 'Design Authoring', which is about process of creating BIM models, considers capabilities of firms (Roadmaps) in: a) defining this process in detail (process mapping), b) defining required model content, and c) technological and human resource support for this process. The KPA of '3D Coordination' considers collision detection and solving capabilities of a firm (Roadmaps) by: a) ability to define this process in detail (process mapping), b) ability to identify information requirements, and c) ability to detect collisions and solving them. The KPA of 'Design Reviews' is a process of reviewing design of BIM model(s) by project stakeholders for model validation. The required capabilities for this process (Roadmaps) include: a) defining this process in detail (process mapping), b) virtual model review conducted by architect, c) constructability review conducted by contractor or construction manager, and d) Operation and Maintenace (O&M) review. The KPA of 'BIM Project Management' considers capabilities of firms for managing BIM in their organization and with other firms. These capabilities are categorized in three subjects (Roadmaps): a) BIM Project Execution Planning capabilities, b) BIM collaboration experience, competencies, and willingness, and c) BIM quality control.

BIM Domain	KPAs	Roadmaps	Discipline(s)	Practice/Question Level 0	Practices/Questions Level 1	Practices/Questions Level 2
Processes	Design Authoring	Detailed process map of Design Authoring	Arch, SE, MEP	1.1.0.1.	1.1.1.1.	1.1.2.1.
		Model content	Arch, SE, MEP		1.1.1.2.	1.1.2.2.
						1.1.2.3.
		Design Authoring required resources	Arch, SE, MEP		1.1.1.3.	1.1.2.4.
						1.1.2.5.
	3D Coordination	Detailed process map of 3D Coordination	All	1.2.0.1.	1.2.1.1.	1.2.2.1.
		Defining 3D Coordination information requirements	All		1.2.1.2.	1.2.2.2.
		Performing collision detection and solving collision problems	All		1.2.1.3.	1.2.2.3.
	Design Reviews	Detailed process map of Design Reviews	Arch, SE, MEP, CM	1.3.0.1.	1.3.1.1.	1.3.2.1.
		Virtual model review	Arch		1.3.1.2.	1.3.2.2.
		Constructability review	Con, CM		1.3.1.3.	1.3.2.4.
		Operation and maintenance (O&M) review	All		1.3.1.4.	1.3.2.4.
	BIM project management	BIM project execution planning	All	1.4.0.1.	1.4.1.1.	1.4.2.1.
		BIM collaboration	All		1.4.1.2.	1.4.2.2.
		BIM quality control	Arch, SE, MEP		1.4.1.3.	1.4.2.3.
Discipline:	Arch: Architecture SE: Structural Engineer MEP: Mechanical, Electrical, Plumbing			Con: Contractor CM: Construction Manager		

Figure 5.5 An overview for KPAs, Roadmaps, and Practices of BIM domain of 'Processes'

The next chapter presents the BIM domain of 'Resources' with its KPAs, Roadmaps, and Practices.

CHAPTER 6

BIM RESOURCES DOMAIN

The domain of ‘Resources’ refers to the required resources to implement BIM in a project. The resources are categorized in the categories of ‘Infrastructure’ and ‘Human resources’.

6.1 Infrastructure KPA

In BIMUMM, the KPA of ‘Infrastructure’ is defined under BIM domain of ‘Resources’ and includes several Roadmaps as shown in Table 6.1.

Table 6.1 Infrastructure Roadmaps

BIM Domain	**KPA**	**Roadmaps**
Resources	Infrastructure	• Software • Hardware • Network

In our proposed model, infrastructure concerns pertain to the technology requirements of BIM implementation for a firm in a project. These technological aspects include software, hardware, and network systems (Succar, 2010a) applicable in BIM processes.

Only when any infrastructure is not allocated to the BIM process in a firm is level zero chosen.

Therefore, **‘Infrastructure’ Resources in Maturity Level 0,** can be described as follows:

Practice 2.1.0.1. The firm has not allocated any infrastructure (software, hardware, network) to BIM activities (Succar, 2010a).

Explanation: In this level, the firm has not allocated any software/hardware/network infrastructure to BIM activities (Succar, 2010a).
Question 2.1.0.1. Has your firm allocated any infrastructure (software, hardware, network) to BIM activities? Yes or No? (If Yes, continue to the next question)

6.1.1 Software

The project team members must identify, determine, and agree upon the software platforms and versions, to perform the BIM Uses which are already determined. The team should define a process to change or upgrade software platforms and versions. The file format for information exchange must be already agreed upon (CIC, 2011).

An important collaborative issue for the project team is the transfer of BIM files by different software. During a project, different disciplines need to review and work on common BIM files. It is important that BIM files work with different software (Indiana University C.1&C.2, 2012). The interoperability concept introduces this collaborative information flow context. In the BIM handbook, Eastman et al. (2011) define interoperability as "the ability of BIM tools from multiple vendors to exchange building model data and operate on that data. Interoperability is a significant requirement for team collaboration and data movement between different BIM platforms". This gives the ability for a change in the model from one discipline to change the calculations of the model in other disciplines (Indiana University C.3, 2012).

The Industry Foundation Class (IFC) is a standard file format for BIM models that allows interoperability, exchange, and sharing of compatible models between different AEC software platforms (McGraw-Hill, 2008; CIC, 2012; Eastman et al., 2011) over the whole lifecycle of building (Eastman et al., 2011). It means that models created in different software tools are translatable to the uniform file format of IFC, and all the model objects' information can be transferred correctly. Therefore, IFC files are compatible with different software applications (McGraw-Hill, 2008). IFC is supported by BuildingSMART, which developed the National BIM Standard of the United States (NBIMS, 2007; 2012).

6.1.1.1 Software Capability in Maturity Level 1

Practice 2.1.1.1. The firm uses BIM software for reading BIM data (Succar, 2010a, p. 88; CIC, 2011, P. 32; CIC, 2012, Organizational BIM Assessment Matrix, category software, level 1; BIM quick scan, question 44).

Explanation: The firm doesn't use BIM software platforms. In this level, software is only capable of reading BIM data (CIC, 2012, Organizational BIM Assessment Matrix, category software, level 1), but they do not provide functionalities to edit the BIM models at this level of capability. Software applications are used in an unmonitored and unregulated way (Succar, 2010a, p. 88).

Question 2.1.1.1. Does your firm use software that can read BIM data? (Choose answer from: No, Partially, Mostly, Yes)

6.1.1.2 Software Capability in Maturity Level 2

Practice 2.1.2.1. The firm determines and standardizes the BIM software platforms to be used within the organization for different BIM tasks (Succar, 2010a, p. 88; CIC, 2011, P. 32; CIC, 2012; BIM quick scan, question 44)

Explanation: The firm determines which BIM software to be used for modeling and the use of software is standardized within the organization (Succar, 2010a). This helps the firm to coordinate the use of software within the organization and avoid problems originating from different software platforms. The software is used not only for accepting BIM data, but also for different tasks, such as creating models, coordination, etc.

Question 2.1.2.1. Does your firm determine and standardize the BIM software platforms to be used within the organization for different BIM tasks? (Choose answer from: No, Partially, Mostly, Yes)

6.1.1.3 Software Interoperability Capability in Maturity Level 2

Practice 2.1.2.2. The firm uses OPEN BIM file formats for information exchange to avoid interoperability issues (CIC, 2011, p. 32; Succar, 2010a, p. 88).
Explanation: The firm determines OPEN BIM file formats, such as IFC, for information exchange and transfer between different disciplines to avoid interoperability issues and provide a better collaborative environment to work with BIM.
Question 2.1.2.2. Does your firm use OPEN BIM file formats for information exchange to avoid interoperability issues? (Choose answer from: No, Partially, Mostly, Yes)

6.1.2 Hardware

Hardware system requirements, such as operating system, CPU type, memory, disk space, video display, etc. (Autodesk [3]), must be considered to operate BIM software applications. The requirements vary depending on the level of usage and the number of users. For example, system requirements for Autodesk Revit 2015 products are defined for different levels, starting from 'Minimum: Entry-Level Configuration' to higher levels (Autodesk [3]), as shown in Appendix III. The hardware specification is important, particularly when information is shared among several disciplines and organizations. It must be ensured that downstream hardware is not less powerful than the hardware that produces the information. To avoid this problem, the hardware should be considered for highest demand and that is most suitable for the majority of BIM Uses (CIC, 2011; Succar, 2010a).

6.1.2.1 Hardware Capability in Maturity Level 1

Practice 2.1.1.2. The firm provides minimum BIM hardware equipment suitable for running basic BIM software (CIC, 2011, p. 32; CIC, 2012, Organizational BIM Assessment Matrix, category hardware, level 1, Succar, 2010a, p. 88; BIM quick scan, retrieved 2015, question 10)

Explanation: In this maturity level, the firm provides minimum required BIM hardware equipment to operate basic BIM software (see Appendix III). However, the hardware specifications are not appropriate or are inconsistent across the firm (CIC, 2011; Succar, 2010a).

Question 2.1.1.2. Does your firm provide minimum BIM hardware equipment suitable for running basic BIM software? (Choose answer from: No, Partially, Mostly, Yes)

6.1.2.2 Hardware Capability in Maturity Level 2

Practice 2.1.2.3. The firm defines and standardizes BIM hardware specifications across the organization, and budgets to provide adequate BIM equipment (CIC, 2011, p. 32; Succar, 2010a, p. 88; BIM quick scan, retrieved 2015, question 10)

Explanation: The firm is capable of defining the required BIM hardware specifications and standardizes it across the organization. Then, the firm allocates enough budget to buy the defined equipment (CIC, 2011; Succar, 2010a; BIM quick scan, retrieved 2015).

Question 2.1.2.3. Does your firm define and standardize BIM hardware specifications across the organization, and budget to provide adequate BIM equipment? (Choose answer from: No, Partially, Mostly, Yes)

6.1.2.3 BIM Infrastructure Upgrade Capability in Maturity Level 2

Practice 2.1.2.4. The firm defines a process for BIM infrastructure upgrades and purchases (CIC, 2011, p. 43; Succar, 2010a, p. 88; BIM quick scan, retrieved 2015, question 10)

Explanation: The firm upgrades its BIM infrastructure, including software and hardware. To identify the required upgrades, the firm defines a process. However, the upgrades and purchases are not targeted or based on the assessment of the current BIM infrastructure and compared to the needs of firm (CIC, 2011; Succar, 2010a).

Question 2.1.2.4. Does your firm define a process for BIM infrastructure upgrades and purchases?

6.1.3 Network

There is a need for a network to share information and communication among project team members (Succar, 2010a). Since the BIM project is a collaborative process, the role of a network is highlighted as a collaboration tool.

6.1.3.1 Network Capability in Maturity Level 1

Practice 2.1.1.3. The firm uses document management or sharing tools, such as a File Transfer Protocol site, Dropbox, Boxnet, web platforms or BIM servers to communicate, store and share data within its organization (Succar, 2010a, p. 88; CIC, 2011, p. 31).
Explanation: The firm is capable of communicating and exchanging files within its organization, and not between other organizations involved in project. The firm uses document management or sharing tools, such as a File Transfer Protocol site, Dropbox, Boxnet, web platforms or BIM servers to communicate, store, and share data (Succar, 2010a). Simple Internet information exchange tools such as email are not considered as BIM exchange tools.
Question 2.1.1.3. Does your firm use document management or sharing tools, such as a File Transfer Protocol site, Dropbox or Boxnet, web platforms or BIM servers to communicate, store, and share data within the organization? (Choose answer from: No, Partially, Mostly, Yes)

6.1.3.2 Network Capability in Maturity Level 2

Practice 2.1.2.5. The firm uses document management or sharing tools, such as a File Transfer Protocol site, Dropbox, Boxnet, web platforms or BIM servers to communicate, store and share data within its organization and between other organizations involved in project (Succar, 2010a, p. 88; CIC, 2011, p. 31) (Succar, 2010a, p. 88; CIC, 2011, p. 31).
Explanation: The firm uses document management or sharing tools, such as a File Transfer Protocol site, Dropbox, Boxnet, web platforms or central BIM servers around the Cloud, to

communicate, store, and share data, not only within its organization, but also between other organizations involved in project. The access level to information can be controlled and defined within and between firms or project members (Succar, 2010a).

Question 2.1.2.5. Does your firm use document management or sharing tools, such as a File Transfer Protocol site, Dropbox, Boxnet, web platforms or BIM servers to communicate, store and share data within its organization and between other organizations involved in project? (Choose answer from: No, Partially, Mostly, Yes)

6.2 Human Resources KPA

In BIMUMM, the KPA of 'Human resources' is defined under BIM domain of 'Resources' and includes several Roadmaps as shown in Table 6.2.

Table 6.2 Human resources Roadmaps

BIM Domain	**KPA**	**Roadmaps**
Resources	Human resources	• Organization roles and staffing • BIM expertise, educational and training programs

Human resources concern the personnel roles and responsibilities and their level of knowledge, skill, and experience. An organization/project's training and educational programs to improve the BIM competency of personnel is also evaluated in this category.

A firm is in level zero of the human resources when no personnel is allocated to perform BIM activities.

Therefore, **'Human Resources' in Maturity Level 0,** can be described as follows:

Practice 2.2.0.1. The firm does not have any personnel for performing BIM activities.

Explanation: There is no BIM specific personnel in the firm, or BIM specific personnel do not have minimum BIM skills and knowledge.

Question 2.2.0.1. Does your firm have any personnel for performing BIM activities? Yes or No? (If Yes, continue to the next question)

6.2.1 Organization roles and staffing

The level of experience and success of the project team with BIM projects is an important factor in BIM implementation success (CIC, 2012, p. 59). The roles and responsibility of personnel involved with BIM implementation must be defined (CIC, 2011, p.29; Succar, 2010a, p.89; CIC, 2012, P. 42, BIM Quickscan, 2015). The requirements and deliverables of individuals on the team must be established and documented. The responsibilities must be divided among the personnel (CIC, 2012, P. 42). Kymmell (2008) proposed three roles to formulate an effective BIM team as follows:

- BIM Manager: "a person who coordinates the team that is responsible for the production and analysis of the BIM";
- BIM Operator: "the actual person doing the work of creating and analyzing the simulation";
- BIM Facilitator: "who will help persons with the viewing and retrieving of information from the BIM".

More details are available in appendix II and appendix IV.

6.2.1.1 Roles and Staffing Capability in Maturity Level 1

Practice 2.2.1.1. The firm has assigned one or several personnel to do BIM tasks in general (CIC, 2011, p. 29; Succar, 2010a, p. 89; BIM quick scan, 2015, question 53).
Explanation: The firm has assigned human resources (personnel) to do BIM tasks in general. The roles and responsibility of personnel in BIM Uses is ambiguous. However, one or several people are responsible for BIM related works.
Question 2.2.1.1. Has your firm assigned one or several people to do BIM tasks in general? (Choose answer from: No, Partially, Mostly, Yes)

6.2.1.2 Roles and Staffing Capability in Maturity Level 2

Practice. 2.2.2.1. The firm defines the roles and responsibilities of involved personnel for each BIM Use (CIC, 2011, p. 29; Succar, 2010a, p. 89; BIM quick scan, 2015, question 53).
Explanation: The BIM tasks include a variety of activities. The firm defines the roles and responsibilities of BIM personnel for each BIM Use and activity.
Question 2.2.2.1. Does your firm define the roles and responsibilities of involved personnel for each BIM Use? (Choose answer from: No, Partially, Mostly, Yes)

6.2.2 BIM expertise, educational and training programs

The level of BIM skill and knowledge of personnel can be increased with training and education programs (Succar, 2010a). CIC (2012, p.44) clarifies the difference between ‘training’ and ‘education’ in its context (Owner BIM organizational execution planning) as follows “Training is to teach so as someone becomes fit, qualified, or proficient in a specific task or process, while educating is to formally instruct about a subject – in this case BIM”.

Kymmell (2008) categorized the required skills for creating and managing a building information model into three categories: a) software tools, b) management processes, and c) project team roles. These categories are detailed more by Kymmell (2008), as follows:

a) Tool-Related skills:

Tool-related learning of BIM applications is focused “on the correct visualization of the objects (and concepts) that are to be modeled, the accuracy with which the objects are represented, and the organization of the model parts” (Kymmell, 2008).

b) Process-Related skills:

Process-related skills are about three processes of ‘Communication’, ‘Information Management’, and ‘Coordination’. The Communication process is improved because all team members see the same 3D virtual building, allowing them to address any issue in the model. Communication management is challenging because of increased collaboration.

Continual evaluation of the communication protocol is important for making required adjustments. Establishing communication channels and monitoring information flow between the team members is also important. In learning the ‘Information Management’ process, BIM exercises should include organizing and editing of information, for example attaching the cost database to physical 3D components. Learning the ‘Coordination’ process includes skills to adjust different elements of project to create a harmonious whole. The most effective tool for virtual coordination is clash detection in 3D models of a building, and this an important part of the exercises. Analysis of the construction sequence of the installation of the underground utilities and the foundation work for a project is another example for required coordination exercises. Proper filtering of information for coordination is also required (Kymmell, 2008).

c) Role-Related skills:

As explained in section 6.2.1, Kymmell (2008) defines the three roles of BIM manager, BIM operator, and BIM facilitator. It is important to exercise each role to better understand the working process of a whole team on a BIM facilitated project. For more information see Section 6.2.1, appendix II, and appendix IV.

6.2.2.1 BIM Expertise, Educational and Training Capability in Maturity Level 1

Practice. 2.2.1.2. The firm has BIM personnel with relevant BIM training and no or low industrial BIM experience (number of years, projects, complexity/magnitude) (BIM quick scan, retrieved 2015, question 19; Succar, 2010a, p. 89).

Explanation: The firm initiates to employ or assign personnel with relevant training in BIM tasks. However, the industrial BIM experience level of personnel is low or zero. The low experience can be defined as no or little years (one or less years) of working with BIM, no or little number of projects using BIM, and working in projects with low complexity/magnitude of BIM aspects.

Question. 2.2.1.2. Does your firm have BIM personnel with relevant BIM training and no or low industrial BIM experience (number of years, projects, complexity/magnitude)? (Choose answer from: No, Partially, Mostly, Yes)

6.2.2.2 BIM Expertise, Educational and Training Capability in Maturity Level 2

Practice. 2.2.2.2. The firm defines the required level of BIM knowledge, skill, and experience of personnel (BIM quick scan, retrieved 2015; Succar, 2010a, p. 89).
Explanation: The firm defines the required level of BIM knowledge, skill, and experience of employees. This capability helps the firm to employ new qualified personnel or train/educate the current personnel to reach the defined level of BIM knowledge, skill, and experience, if needed.
Question 2.2.2.2. Does your firm define the required level of BIM knowledge, skill, and experience of personnel? (Choose answer from: No, Partially, Mostly, Yes)

Practice 2.2.2.3. The firm identifies the required BIM educational and training programs for its BIM personnel (Succar, 2010a, p. 90; BIM quick scan, retrieved 2015, question 22).
Explanation: In this level, the firm is capable of identifying the educational/training needs of its BIM personnel. Based on the identified needs, the firm defines BIM educational and training programs for its BIM personnel to improve their level of BIM skills and expertise (Succar, 2010a; BIM quick scan, retrieved 2015).
Question 2.2.2.3. Does your firm identify the required BIM educational and training programs for its BIM personnel? (Choose answer from: No, Partially, Mostly, Yes)

6.3 Conclusion

As indicated in Figure 6.1, BIM domain of ‘Resources’ includes two KPAs, a total of 5 ‘Roadmaps’, and 15 practices/questions in 3 maturity levels of 0, 1, and 2. In this BIM domain the Roadmaps are not specific to any discipline and belongs to all disciplines. In the proposed model, the KPA of ‘Infrastructure’ considers the required technological infrastructure of a firm to implement BIM in a project. The capability to provide technology infrastructure requirements is considered in three areas (Roadmaps) of: a) software, b) hardware, and c) network. The KPA of ‘Human Resources’ considers BIM competency level of personnel of firms and personnel management. These capabilities are identified in two categories (Roadmaps) of: a) Organization roles and staffing, and b) BIM expertise, educational and training programs.

BIM Domain	KPAs	Roadmaps	Discipline(s)	Practice/Question Level 0	Practices/Questions Level 1	Practices/Questions Level 2
Resources	Infrastructure	Software	All	2.1.0.1.	2.1.1.1.	2.1.2.1.
						2.1.2.2.
		Hardware	All		2.1.1.2.	2.1.2.3.
						2.1.2.4.
		Network	All		2.1.1.3.	2.1.2.5.
	Human resources	Organization roles and staffing	All	2.2.0.1.	2.2.1.1.	2.2.2.1.
		BIM expertise, educational and training programs	All		2.2.1.2.	2.2.2.2.
						2.2.2.3.
Discipline:	Arch: Architecture SE: Structural Engineer MEP: Mechanical, Electrical, Plumbing			Con: Contractor CM: Construction Manager		

Figure 6.1 An overview for KPAs, Roadmaps, and Practices of BIM domain of ‘Resources’

The next chapter presents the BIMUMM validation method and results.

CHAPTER 7

MODEL VALIDATION

7.1 BIMUMM Focus Group Validation

For validation of the BIMUMM model, a focus group method was chosen to get the opinions of participants. The focus group participants included four people from industry and academia as indicated in Table 7.1.

Table 7.1 Focus group participant information

Participants	**Organization**	**Role**	**Highest academic degree**
Participant 1	General Contractor	BIM director	PhD, Post Doc./Architecture
Participant 2	General Contractor	BIM MEP coordinator	B.Eng/Mechanic
Participant 3	Academia	Research associate	PhD, Post Doc/Architecture
Participant 4	Academia	Researcher	PhD/Architecture

The focus group meeting was conducted with the following activities flow:

1) Presentation of BIMUMM purpose, architecture, maturity level definition of 0 to 2, and logic;
2) Asking the opinion of participants regarding BIMUMM architecture;
3) Six Key Process Areas (KPAs), including ‘Design Authoring’, ‘3D coordination’, ‘Design reviews’, ‘BIM management’, ‘Infrastructure’, and ‘Human resources’, were presented with their subjects and the questions about the maturity assessment of those subjects. For each KPA, the following questions were asked of the participants:

- What's your opinion regarding the subjects to be assessed in this KPA?
- What's your opinion regarding the maturity assessment questions of this KPA?

7.2 Validation Results

In the focus group meeting, the participants discussed, gave their opinions regarding the initial version of the proposed model (BIMUMM v.0) and provided some recommendations. The researcher (focus group moderator) analyzed the information provided in the meeting and did different actions on them: a) accepted for revision: the comment is used to modify the practice(s); b) partially accepted for revision: the comment is used partly to modify the practice(s), because of a reason; c) left for future researchs, because of a reason. Table 7.2 indicates an overview of the model validation steps and concepts.

Table 7.2 An overview of model validation steps and concepts

Submitted questionnaire	**Comments**	**New questionnaire**
BIMUMM v.0 was submitted to focus group participants as shown in Appendix VI.	The focus group comments and the actions on them are summarized in section 7.2.	New version of model, BIMUMM v.1 is presented in chapters 5 and 6. The new version is based on analyzing focus group comments, literature review, and new revisions.

Through focus group validation, BIMUMM v.0 was presented to the participants and they commented on the potential improvement of the model.

The major applicable points for BIMUMM improvement are listed as follows:

Design Authoring KPA:

- In the BIM maturity assessment, Design Authoring BIM models should be considered for all disciplines (architecture, structure, MEP) or for firms with different disciplines. Action on the comment: accepted for revision.
- ‘Model content’ should be the first level of maturity questions because in the industry, very often we see that somebody starts modeling without understanding the process or responsibilities. Action on the comment: accepted for revision.
- Based on the importance of each question for each type of company, a weight can be given to that question. In this way, the questionnaire would not be biased. For example, if we are assessing a firm specializing in mechanical engineering, it is not important if it is capable of doing architectural activities. The weighting scale of 0 to 10 is recommended. Action on the comment: left for future researchs (reason: needs a completed model).

3D Coordination KPA:

- 3D coordination is not only clash detection and covers other activities. Action on the comment: left for future researchs (reason: out of scope of this research).
- Good clash detection depends on good models, which are created in Design Authoring process. This can be seen in ‘information requirement’. Action on the comment: accepted for revision.

Design Review KPA:

- Design Review covers BIM models of all disciplines. Action on the comment: accepted for revision.
- Design Review needs integrated models of all disciplines. Action on the comment: accepted for revision.
- The level of detail for its BIM models should be defined for each company. Action on the comment: accepted for revision.
- For the Operation & Maintenance (O&M) Design Review, in level 1, the firm should make sure the required BIM information is available. In level 2, the O&M information should be implemented in the Design Review. Action on the comment: accepted for revision.

BIM Project Management:

- BIM management should be considered in two levels: a) company level, b) project level. Action on the comment: accepted for revision.
- BIM execution planning refers to the project level. Action on the comment: accepted for revision.
- The recommended questions about BIM execution planning are: Level 1: Do you have a template in your company for project execution planning? Level 2: Do you assist in project execution planning with other firms? Action on the comment: partially accepted for revision (BIM manager is replaced with template, because BIM manager develops template).

Infrastructure:

- Access to the Internet and using communication and sharing tools such as email or videoconference is not considered part of BIM infrastructure and should be considered at level 0. Action on the comment: accepted for revision.

- For communication, storing, and sharing data, level 1 can be within the company and office; level 2 can be within and between companies and offices. Action on the comment: accepted for revision.
- Storing BIM data can be considered as level 1 for a company whose central server is on the Cloud. Action on the comment: accepted for revision.
- A system for the assessment of current BIM infrastructure compared with needs for upgrading and purchasing is considered at level 3. Action on the comment: partially accepted for revision (reason: at level 2, upgrades and purchases can be defined in a firm, but not efficiently).

Human resources:

- It should be mentioned whether the type of training and experience is with BIM or not. Action on the comment: accepted for revision.
-

7.3 Conclusion

The model validation is based on a foucs group meeting with four participants. The initial version of the proposed model, BIMUMM v.0, was submitted to focus group participants and they provided feedback and comments about the model. Then the researcher analyzed the provided information, reviewed the literature again, and did different actions on the comments and recommendations of focus group participants, to develop a revised version of model, namely BIMUMM v.1. The validation process in this research has some limitations: a) the number of participants in focus group was four people (2 from industry, 2 from academia), because of the limited access to BIM experts; b) only one meeting of focus group was conducted, because of the limited time of the research; c) the model couldn’t be tested in a real case, because of the limited time and limited access to BIM experts. However, the validation could provide an initial verification of a four people group of BIM experts and potential improvements of the model.

CONCLUSION

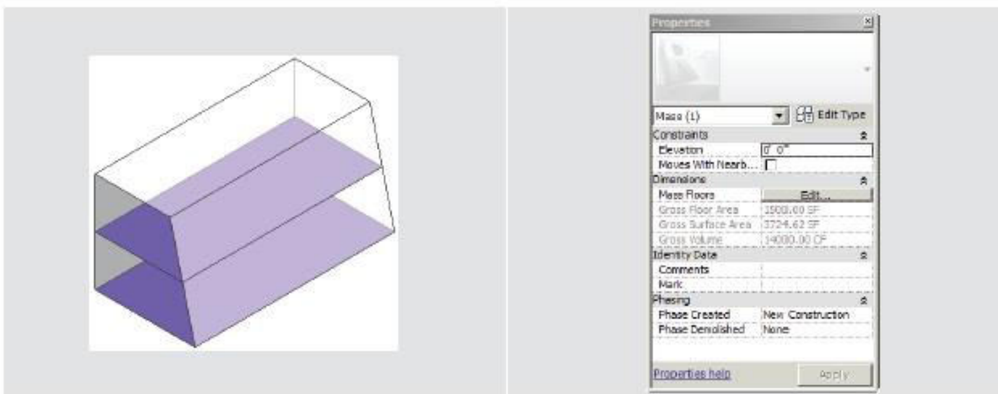
Construction clients need a mechanism to ensure that the participating firms of project meet minimum BIM requirements to qualify to do a project. From the perspective of a client, 'minimum BIM qualification' can be translated to 'minimum capability to use BIM'. This perspective offers a new opportunity for a novel BIM maturity model and its independent certification process. There is a lack in the current BIM maturity models to consider BIM through this lens. This research focuses on the 'BIM Process' and 'BIM Resources' domains of the construction industry to address the construction clients' concern regarding the assessment of minimum BIM capabilities of potential project participants. This research proposed initial practices of a proposed BIM uses maturity model for prequalification assessment of construction project applicants. The proposed model has a hierarchical architecture, from most general to most specific practices, namely 'BIM domains', KPAs, Roadmaps, and practices. The main contribution of the proposed maturity model is to focus on the BIM maturity assessment of key 'BIM Uses'. Three most frequent BIM Uses, including 'Design Authoring', '3D Coordination', and 'Design Reviews' have been selected from 25 inventoried BIM uses, as KPAs in this model prototype. In addition, general KPAs namely 'BIM project management', 'Infrastructure', and 'Human resources' have been defined and detailed in this first version of the model. Further work will need to be done in order to validate further this model proposal. First, the other model practices will need to be developed. Then, an assessment process will need to be developed to assess the current BIM maturity level of firms for each KPA using the 5-levels scale and providing a detailed assessment report. This assessment process should use and validate the questionnaire proposed by this research. Other future research can also be conducted on 1) improving the current model practices by further validating the model in real cases studies; 2) developing additional BIM uses, as new KPAs as required; and 3) developing the model in higher levels of 3 to 5. By employing more BIM qualified or BIM certified firms in construction industry, researchers would expect to improve productivity in this industry and demonstrate more competitive advantages and BIM benefits in the future. Finally, in the long terms, this BIM uses maturity model could be used to assess the eligibility of a supplier to participate in a construction project. To be eligible to participate in a construction project bid where the client requires BIM, interested firms would need to be pre-certified at a certain BIM maturity level. A recognized third party assessment body could conduct assessements and issue certificates.

APPENDIX I

Level of Development in alignment with AIA – Exhibit 202 Document

LOD 100

Level 100 Models include elements such as Masses and are used for preliminary studies, such as Conceptual Design and Overall Project Phasing. Analysis based on their Location and Orientation can be performed. Quantities based on Overall Area and Overall Volume can be obtained.

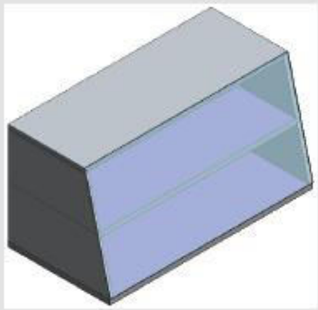


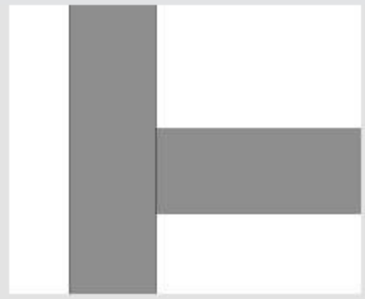
The images above show the Building Elements as Masses and its associated Area and Volume.

Figure-A I-1 Level of Development (LOD) 100
Taken from DDC (2012)

LOD 200

Level 200 Models include elements in which Masses have been replaced with Generic Components. Analysis based on Overall Systems can be performed. Quantities based on specific Elements can be obtained.





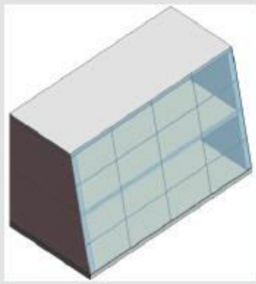
Wall Schedule (LoD-2)					
Family	Type	Width	Length	Area	Volume
Basic Wall	Generic - 8"	0' - 8"	39' - 0"	656 SF	437.51 CF
Basic Wall	Generic - 12"	1' - 0"	39' - 4"	759 SF	759.22 CF

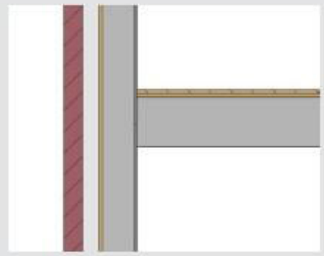
The images above show the different Building Elements as Generic Components. The major characteristics of components are their thickness and width allowing quick takeoffs.

Figure-A I-2 Level of Development (LOD) 200
Taken from DDC (2012)

LOD 300

Level 300 Models include elements in which Generic Components have been replaced with fully defined Assemblies. Analysis based on Specific Systems can be performed. Quantities based on Materials can be obtained.





Wall Material Takeoff (LoD-3)	
Material: Name	Material: Volume
Gypsum Wall Board	58.66 CF
Masonry - Brick	425.26 CF
Metal - Stud Layer	703.87 CF
Misc. Air Layers - Air Space	351.94 CF
Wood - Sheathing - plywood	87.98 CF

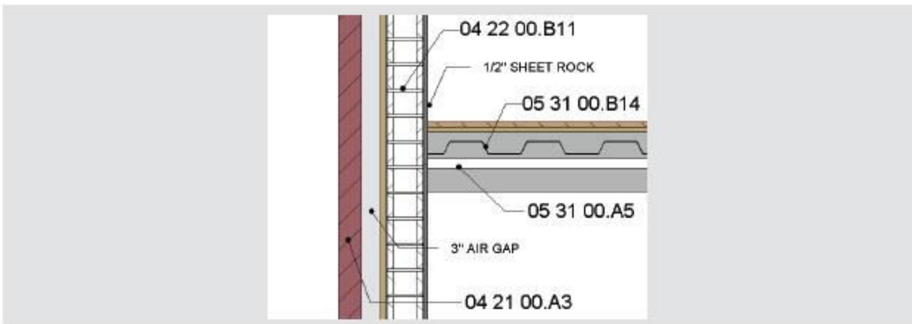
The images above show the different Building Elements as fully defined Assemblies, where the different components have well-defined characteristics; therefore a more specific takeoff can be performed.

At LOD 300 the model can be leveraged for the generation of traditional Construction Documents and Shop Drawings. The model can be used for analysis such as: Energy Performance, Clash & Cost.

Figure-A I-3 Level of Development (LOD) 300
Taken from DDC (2012)

LOD 400

Level 400 Models include elements that are accurate in terms of size, shape, location, quantity and orientation with complete fabrication, assembly and detailing information. At this Level, the Model may also have non-geometric (3D) information such as text, dimensions, notes, 2D details, etc.



The image above shows a detail where 2D information has been placed on top of the 3D Model on a Section View.

At LOD 400 the model is a representation of the proposed elements. Analysis can be performed such as: Energy Performance, Clash Detection, and Sequencing & Cost.

Figure-A I-4 Level of Development (LOD) 400
Taken from DDC (2012)

LOD 500

Level 500 Models includes elements modeled as constructed. Elements are modeled to accurate size, shape, location and orientation. Non geometric or physical attributes are included as parameters to the geometric shape. At this level, model granularity is similar to LOD 400 with the exception that elements are as-constructed.

At LOD 500, the model is capable of being utilized for operations and maintenance.

element_ID	revit_ID	last_inspected	next_inspection_due_date	priority	condition
132457383	659832	6/2/2008	9/11/2011	medium	good
132426790	679334	6/2/2008	9/11/2011	medium	good
132447782	650023	6/2/2008	9/11/2011	medium	good
131276003	672363	4/20/2006	1/24/2011	high	fair
132786522	650933	6/2/2008	9/11/2011	medium	good
131028862	667681	6/2/2008	9/11/2011	medium	good
132290073	679911	6/2/2008	9/11/2011	medium	excellent
131189520	640087	6/2/2008	9/11/2011	medium	good

Figure-A I-5 Level of Development (LOD) 500
Taken from DDC (2012)

APPENDIX II

BIM Manager roles and responsibilities

Table-A II-1 BIM manager roles and responsibilities
Taken from Joseph (2011)

BIM Manager – Depending on the organization size, sometimes merging BIM Management and Director roles into one position. However, it is worth mentioning that irrelevant of the firm size, it is rather difficult to manage the daily BIM Management duties while preforming the responsibilities of a managing director responsible for growing a line-of-service extension and educating an entire firm. Balancing that with having to create parametric REVIT® families isn't really realistic. Project Template Set-up: Setting up projects from scratch with company BIM standards, making early decisions on how to break-up the models and distribute them based on design and construction team needs, geographical location and collaboration requirements. Finally lead BIM Kick-off meetings. Model Management: Rotate through projects to police standards, ensure that modeling is done properly and model sizes are kept at a minimum. Fluency in all REVIT® flavors is critical to ensure interoperability between the modeling products and to pass on critical information to BIM Applications Specialists and the Job Captains. Coaching and Developing: establishing training material under the direction of BIM Director and conducting software training with own BIM Applications Specialists team to grow skills as well as project teams. Performing on-site real project shadowing to staff of all disciplines to help them execute skills from training sessions.

Table-A II-1 (continued) BIM manager roles and responsibilities
Taken from Joseph (2011)

Essential Responsibilities :
- Developing Marketing BIM Material: Images, Animations
- BIM Content Management, Creation, Approval and Procedures
- Establish documented processes, procedures and workflows
- Interoperability Management of BIM and design / engineering tools
- Proactive approach and learning of new technology software

APPENDIX III

System requirements for Autodesk Revit 2015 products

Minimum: Entry-Level Configuration	
Operating System [1]	**Microsoft® Windows® 7 SP1 64-bit**: Windows 7 Enterprise, Ultimate, Professional, or Home Premium **Microsoft® Windows® 8 64-bit**: Windows 8 Enterprise, Pro, or Windows 8 **Microsoft® Windows® 8.1 64-bit**: Windows 8.1 Enterprise, Pro, or Windows 8.1
CPU Type	Single- or Multi-Core Intel® Pentium®, Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology. Highest affordable CPU speed rating recommended. Autodesk® Revit® software products will use multiple cores for many tasks, using up to 16 cores for near-photorealistic rendering operations.
Memory	4 GB RAM • Usually sufficient for a typical editing session for a single model up to approximately 100 MB on disk. This estimate is based on internal testing and customer reports. Individual models will vary in their use of computer resources and performance characteristics. • Models created in previous versions of Revit software products may require more available memory for the one-time upgrade process.
Video Display	1,280 x 1,024 with true color
Video Adapter	**Basic Graphics**: Display adapter capable of 24-bit color **Advanced Graphics**: DirectX® 11 capable graphics card with Shader Model 3 as recommended by Autodesk.
Disk Space	5 GB free disk space
Media	Download or installation from DVD9 or USB key
Pointing Device	MS-Mouse or 3Dconnexion® compliant device
Browser	Microsoft® Internet Explorer® 7.0 (or later)
Connectivity	Internet connection for license registration and prerequisite component download

Figure-A III-1 System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

Value: Balanced price and performance	
Operating System [1]	**Microsoft® Windows® 7 SP1 64-bit:** Windows 7 Enterprise, Ultimate, Professional, or Home Premium **Microsoft® Windows® 8 64-bit:** Windows 8 Enterprise, Pro, or Windows 8 **Microsoft® Windows® 8.1 64-bit:** Windows 8.1 Enterprise, Pro, or Windows 8.1
CPU Type	Multi-Core Intel® Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology. Highest affordable CPU speed rating recommended. Autodesk® Revit® software products will use multiple cores for many tasks, using up to 16 cores for near-photorealistic rendering operations.
Memory	8 GB RAM • Usually sufficient for a typical editing session for a single model up to approximately 300 MB on disk. This estimate is based on internal testing and customer reports. Individual models will vary in their use of computer resources and performance characteristics. • Models created in previous versions of Revit software products may require more available memory for the one-time upgrade process.
Video Display	1,680 x 1,050 with true color
Video Adapter	DirectX® 11 capable graphics card with Shader Model 3 as recommended by Autodesk.
Disk Space	5 GB free disk space
Media	Download or installation from DVD9 or USB key
Pointing Device	MS-Mouse or 3Dconnexion® compliant device
Browser	Microsoft® Internet Explorer® 7.0 (or later)
Connectivity	Internet connection for license registration and prerequisite component download

Figuere-A III-1 (continued) System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

Performance: Large, complex models	
Operating System [1]	**Microsoft® Windows® 7 SP1 64-bit:** Windows 7 Enterprise, Ultimate, Professional, or Home Premium **Microsoft® Windows® 8 64-bit:** Windows 8 Enterprise, Pro, or Windows 8 **Microsoft® Windows® 8.1 64-bit:** Windows 8.1 Enterprise, Pro, or Windows 8.1
CPU Type	Multi-Core Intel® Xeon®, or i-Series processor or AMD® equivalent with SSE2 technology. Highest affordable CPU speed rating recommended. Autodesk® Revit® software products will use multiple cores for many tasks, using up to 16 cores for near-photorealistic rendering operations.
Memory	16 GB RAM • Usually sufficient for a typical editing session for a single model up to approximately 700 MB on disk. This estimate is based on internal testing and customer reports. Individual models will vary in their use of computer resources and performance characteristics. • Models created in previous versions of Revit software products may require more available memory for the one-time upgrade process.
Video Display	1,920 x 1,200 with true color
Video Adapter	DirectX® 11 capable graphics card with Shader Model 3 as recommended by Autodesk.
Disk Space	5 GB free disk space 10,000+ RPM (for Point Cloud interactions) or Solid State Drive
Media	Download or installation from DVD9 or USB key
Pointing Device	MS-Mouse or 3Dconnexion® compliant device
Browser	Microsoft® Internet Explorer® 7.0 (or later)
Connectivity	Internet connection for license registration and prerequisite component download

Figuere-A III-1 (continued) System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

Citrix®: Recommended-Level Configuration [2]	
Citrix System	XenApp® 6.0 XenApp® 6.5 Feature Pack 2 Citrix® License Manager Citrix® Profile Manager
Server OS	As specified by XenApp® system requirements
Authentication	Microsoft® Active Directory • Roaming Profiles supported
Client OS	Microsoft® Windows® 7 SP1 64-bit Microsoft® Windows® 8 64-bit Microsoft® Windows® 8.1 64-bit
Client Browser	Microsoft® Internet Explorer® 7.0 (or later)
User Access	Client computers should be bound to the network domain. Each client computer should have either the full Citrix® or web client plug-in installed. Users should use their domain logins to access both the Citrix web console and the LAN.

Figuere-A III-1 (continued) System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

Parallels Desktop® 9 for Mac: Recommended-Level Configuration	
Host Operating System & Hardware Type	Mac® OS X® 10.9.1 "Mavericks" MacBook Pro® 10,1 (Early 2013) 13.3 or newer
Memory	16 GB
CPU Type	2.7 GHz quad-core Intel® Core i7™ recommended
Virtualization Software	Parallels Desktop® 9.0.24172 for Mac or newer
Virtual Machine Operating System [1]	**Microsoft® Windows® 7 SP1 64-bit**: Windows 7 Enterprise, Ultimate, Professional, or Home Premium **Microsoft® Windows® 8 64-bit**: Windows 8 Enterprise, Pro, or Windows 8 **Microsoft® Windows® 8.1 64-bit**: Windows 8.1 Enterprise, Pro, or Windows 8.1
Virtual Machine Browser	Microsoft® Internet Explorer® 7.0 (or later)
Virtual Machine Memory	8 GB RAM • Usually sufficient for a typical editing session for a single model up to approximately 100 MB on disk. This estimate is based on internal testing and customer reports. Individual models will vary in their use of computer resources and performance characteristics. • Models created in previous versions of Revit software products may require more available memory for the one-time upgrade process.
Virtual Machine Video Adapter	512 MB video memory minimum dedicated to the Microsoft® Windows® Virtual Machine. **Note**: While at Retina® display resolutions on the Mac OS, turn off any Retina Resolution options in Parallels Desktop to adjust for proper DPI within Windows and Revit software products. **Graphics**: Parallels Desktop virtual display adapter without "Use Hardware Acceleration" option in Revit software products.
Video Adapter	NVIDIA® GeForce® GT 650M or newer 2,880 × 1,800 with 24-bit color (see Virtual Video Adapter note)
Disk Space	Minimum 40 GB free disk space; recommend 100 GB free disk space available
Pointing Device	MS-Mouse or 3Dconnexion® compliant device
Media	Download or installation from DVD9 or USB key
Connectivity	Internet connection for license registration and prerequisite component download

Figuere-A III-1 (continued) System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

System requirements for Autodesk® Revit® Server 2015			
Operating System	Microsoft® Windows Server® 2008 R2 SP1 64-bit Microsoft® Windows Server® 2012 64-bit Microsoft® Windows Server® 2012 R2 64-bit		
Web Server	Microsoft® Internet Information Server 7.0 (or later)		
CPU Type	4+ cores 2.6 GHz+	6+ cores 2.6 GHz+	6+ cores 3.0 GHz+
<100 Concurrent Users (multiple models)	**Minimum**	**Value**	**Performance**
Memory	4 GB RAM	8 GB RAM	16 GB RAM
Hard Drive	7,200+ RPM	10,000+ RPM	15,000+ RPM
100+ Concurrent Users (multiple models)	**Minimum**	**Value**	**Performance**
Memory	8 GB RAM	16 GB RAM	32 GB RAM
Hard Drive	10,000+ RPM	15,000+ RPM	High-Speed RAID Array
Virtualization	VMware® and Hyper-V® Support (See Revit Server Administrator's Guide)		

Figuere-A III-1 (continued) System requirements for Autodesk Revit 2015 products
Taken from (Autodesk [3])

APPENDIX IV

The roles in a BIM team

Table-A IV-1 The roles in a BIM team
Taken from Kymmell (2008, p. 147-148)

BIM Manager The BIM manager will be a"people person" who is able to communicate on a personal level and quickly assess how to improve collaboration on all levels among the team members and outside contacts. She or he is the strategic planner of the project. It is the role of the BIM manager to determine how the BIM can best serve the particular project. The critical factors will be the client's requirements or wishes, the experience of the project team, and the availability of resources (personnel, software training, tools, etc.) The goals for the BIM process need to be analyzed and evaluated by the BIM manager so that a plan can be developed. This role requires thorough knowledge of the processes and tools necessary to create and analyze the BIM. Direct modeling experience is not required, but an understanding of the process and its limitations is important to optimize the planning of the project. A BIM manager's plan will contain the following: • Who will model and what tools will be used? • What will be modeled and to what level of detail? • What information will be required and who will provide it? • Which analytic processes will be required and who will perform them? • How the models will be structured and detailed to make the analysis possible? • What the time frame will be for the various milestones of the BIM production?

Table-A IV-1 (continued) The roles in a BIM team
Taken from Kymmell (2008, p. 147-148)

BIM Operators

The BIM operators are the BIM team members who are involved in the production and analysis of the BIM. This will include all designers and consultants who build 3D models of their parts of the work, as well as all others who interact with the BIM from any informational standpoint, ie estimators, schedulers, fabricators, etc. These persons have to be very familiar with all aspects of the tools required for their work. No effort should be spared to adequately train in the use of such tools. Generally much more time and effort is wasted in inefficient use of a tool than would have been spent properly training for it. Training is the most likely area where shortcuts appear attractive, but consequently also where the largest inefficiencies can result.

BIM Facilitator

It is likely that the BIM will primarily be planned and created in the office, but that it will also be extensively used on the jobsite for management purposes. There is an advantage to separating these two functions so that the BIM can be more fully integrated into various construction site operations. It is powerful to have a BIM at job meetings where the discussions can be aided with the visualization and communication advantages of the 3D model and its possibilities. A BIM facilitator would be primarily jobsite-based and would facilitate the use of the BIM by those physically constructing the project. He or she would be instrumental in aiding the superintendent to establish communications with, and among, the subcontractors. This role will require understanding of the viewing software and the structure of the component models. The facilitator will help the retrieval of information from the BIM at the jobsite. He or she will navigate through the model and help the builders to understand their work better with the aid of the BIM visualization.

APPENDIX V

Project owner's questions about BIM qualifications of project

Table-A V-1 Project owner's questions about BIM qualifications of project applicants
Taken from CIC (2012, p. 58)

Number	Question
1	Describe how your firm plans to use BIM on this project including proposed BIM Uses, processes, information exchanges, and collaboration procedures.
2	Provide an example of a project(s) in which you previously implemented BIM. Provide the following information for each project: a) Project Name; b) Building Type; c) Brief Project Description; d) Project size and value; e) Location; f) Completion Date; g) Description of value added through BIM implementation
3	Provide a completed BIM Project Execution Plan for project mentioned in item 2. If no BIM plan was used, provide detailed description of how BIM was used in project. Be sure to include roles and responsibilities, BIM Uses implemented, collaboration between project participants, and deliverables. Requiring a BIM plan within the qualifications/proposal submission greatly increases the size of the submission, but provides the owner with important evidence as to the true qualifications of the project team.
4	Describe standard BIM practices on typical projects.

APPENDIX VI

BIMUMM v.0 presented in focus group

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Processes	Design Authoring	1.1.0.1. Does your firm perform any Design Authoring activity? Yes or No?	1.1.1.1. Does your firm develop a process map in order to identify Design Authoring activities and their relation, responsible parties, and information requirements and flow?	1.1.2.1. Is your firm capable of creating BIM models with general size and location, and parametric objects?
			1.1.1.2. Is your firm capable of creating BIM models, with basic data (schematic size and location) for 3D visulization of building?	1.1.2.2. Does your firm has Design Authoring software infrastructure (i.e. Revit Architecture, Revit Structure, Tekla Structure, Revit MEP), in all disciplines, for creating and integrating 3D model of building in projects?
			1.1.1.3. Does your firm has minimum Design Authoring software infrastructure (i.e. Revit Architecture, Revit Structure, Tekla Structure, Revit MEP) for 3D visualization of building in your projects?	

Figure-A VI-1 BIMUMM v.0 questionnaire

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Processes	3D Coordination	1.2.0.1. Does your firm perform any 3D Coordination activity? Yes or No?	1.2.1.1. Does your firm develop a process map in order to identify 3D Coordination activities and their relation, responsible parties, and information requirements?	1.2.2.1. Does your firm carry out regular clash check between Architectural, Structural, and Mechanical, Engineering and Plumbing (MEP) building models?
			1.2.1.2. Is your firm capable to carry out clash check between Architectural, Structural, and Mechanical, Engineering and Plumbing (MEP) building models?	1.2.2.3. Has your firm defined a protocol to address the detected clashes ?
			1.2.1.3. Does your firm define the schedule and location of clash detection meetings in order to review and discuss on the clash problem and address it?	

Figure-A VI-1 (continued) BIMUMM v.0 questionnaire

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Processes	Design Reviews	1.3.0.1. Does your firm perform any Design Reviw activity? Yes or No?	1.3.1.1. Does your firm develop a process map in order to identify 'Design Review' activities and their relation, responsible parties, and information requirements?	1.3.2.1. Is your firm capable to provide an architectural virtual mockup of building model, with medium level of detail (Level B), for Design Review by project stakeholders?
			1.3.1.2. Is your firm capable to provide an architectural virtual mockup of building model, with low level of detail (Level C), for Design Review by project stakeholders?	1.3.2.2. Does your firm provide an integrated multi-discipline 3D model, for Operation and Management (O&M) review of facility owner or its representatives?
				1.3.2.3. Does your firm perform constructability review by using an integrated multi-disciplinary BIM model?

Figure-A VI-1 (continued) BIMUMM v.0 questionnaire

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Processes	BIM project management	1.4.0.1. Does your firm define and conduct any BIM Project Management activity? Yes or No?	1.4.1.1 Does your firm has experience of collaboration with other firms to deliver BIM services/products?	1.4.2.1 Has your firm ever assisted in BIM project execution planning process with other firms involved in project?
			1.4.1.2 Does your firm performs 'Visual Check' for BIM quality control purposes and in order to avoid unintended model components?	1.4.2.2 Does your firm perform 'Element Validation' for BIM quality control purposes and in order to avoid undefined or incorrectly defined elements?

Figure-A VI-1 (continued) BIMUMM v.0 questionnaire

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Resources	Infrastructure	2.1.0.1. Has your firm allocated any infrastructure to BIM activities? Yes or No?	2.1.1.1. Has your firm has initiated to use BIM software to create BIM models?	2.1.2.1. Does your firm determine and unify the BIM software platforms to be used within the organization?
			2.1.1.2. Has your firm initiated to provide BIM hardware equipement to operate available software?	2.1.2.2. Does your firm define file formats for information exchange to avoid interoperability issues?
			2.1.1.3. Does your firm use any electronic tool, such as email, video-conference, hard disk, etc. to communicate and share data?	2.1.2.3. Does your firm define and standardize BIM hardware specifications accros the organization, and budgets to provide adequate BIM equipment?
				2.1.2.4. Does your firm have a system for BIM infrastructure assessment and compare the needs to the current situation and make necessary upgrades and purchases?
				2.1.2.5. Does your firm use a unified network solution to share data and communicate within the firm and with other project team members?

Figure-A VI-1 (continued) BIMUMM v.0 questionnaire

BIM Domain	KPAs	Question Level 0	Questions Level 1	Questions Level 2
Resources	Human resources	2.2.0.1. Does your firm have any personnel for performing BIM activities? Yes or No?	2.2.1.1. Has your firm assigned one or several personnel to do BIM tasks in general?	2.2.2.1. Does your firm define the roles and responsibilities of involved personnel for each BIM Use?
			2.2.1.2. Does your firm has BIM personnel with relevant expertise and no or low experience (number of years, projects, complexity/magnitude)?	2.2.2.2. Does your firm define the required level of BIM knowledge, skill, and experience of personnel?
				2.2.2.3. Does your firm define the required BIM educational and training programs for its BIM personnel?

Figure-A VI-1 (continued) BIMUMM v.0 questionnaire

APPENDIX VII

Glossary

BIM Competency: The ability of doing BIM-related practices successfully and efficiently

BIM Maturity: "Quality, repeatability and degree of excellence within a BIM capability" (Succar et al, 2012, p. 124)

BIM Use: «A unique task or procedure on a project which can benefit from the integration of BIM into that process » (CIC, 2011, p. 1)

BIM project execution plan: A document that lays out how BIM will be executed on the project as a result of the decision of the group (CIC, 2011).

Key Process Area: A cluster of related practices in an area of BIM that, when performed collectively, achieve a set of goals considered important for establishing process capability in that area (adapted from April, 2005).

Maturity model: "A conceptual framework, with constituent parts, that defines maturity in the area of interest. […] In some cases, […], a maturity model may also describe a process whereby an organization can develop or achieve something desirable, such as a set of Capabilities or practices" (OPM3, 2003, p. 5)

Practice: "A technical or management activity that contributes to the creation of the output of a process or enhances the capability of a process" (April, 2005, p. 235)

Process: "A series of activities (tasks, steps, events, operations) that takes an input, adds value to it, and produces an output (product, service, or information) for a customer" (Anjard, 1998, p. 79). A process also uses resources (April, 2005).

Process map: “A visual aid for picturing work processes which shows how inputs, outputs and tasks are linked” Anjard (1998, p. 79).

Roadmap: “A set of linked practices that can often cover many levels of maturity” (April 2005, p. 76)

LIST OF REFERENCES

Amiri, H. 2012. *Building Information Modeling For Construction Applications: Formwork Installation And Quantity Takeoff*. Master Thesis, UBC.

Anjard, R. 1998. *Process mapping: a valuable tool for construction management and other professionals*. Facilities, Vol. 16 Iss: 3/4, pp.79 - 81

April, A. 2005. *S^{3M}-Model to Evaluate and Improve the Quality of Software Maintenance Process*, PhD thesis. Germany.

April, A., Coallier, F. 1995. *Trillium: A Customer-Oriented Assessment Method for Software System Development Capability*. Proceedings Quebec-German Workshop on Software Measurement, Bonn.

Autodesk [1]. *Revit Enhanced MEP systems*. Retrieved from http://www.autodesk.com/products/revit-family/features/mep-engineering/all/gallery-view, on January 10, 2015

Autodesk [2]. *Autodesk Navisworks Manage*. Retrieved from http://www.autodesk.com/products/navisworks/features/all/gallery-view. On January 10, 2015

Autodesk [3]. *System requirements for Autodesk Revit 2015 products, November 2014*, Retrieved from http://knowledge.autodesk.com/support/revit-products/troubleshooting/caas/sfdcarticles/sfdcarticles/System-requirements-for-Autodesk-Revit-2015-products.html#revitserver. on June 20, 2015

Autodesk [4]. *BIM 360 Glue Step-by-Step: From Upload to Clash Detection*. Retreived from http://auworkshop.autodesk.com/library/bim-curriculum-construction-cloud. On July 11, 2015

Barlish, K., Sullivan, K., 2012. *How to measure the benefits of BIM — A case study approach*, Automation in Construction 24, 149–159.

BIM Quick Scan Tool. 2012. *BIM Quick Scan Tool, Self scan questionnaire*. Retrieved from http://www.bimquickscan.nl on February 15, 2015.

CIC. 2011. Computer Integrated Construction Research Program. *"BIM Project Execution Planning Guide – Version 2.1."* May, The Pennsylvania State University, University Park, PA, USA. Retrieved from http://bim.psu.edu on January 12, 2015.

CIC. 2012. Computer Integrated Construction Research Program. *"BIM Planning Guide for Facility Owners"*. Version 1.01, May, The Pennsylvania State University, University Park, PA, USA. Retrieved from http://bim.psu.edu on January 12, 2015.

Cox, A., and Ireland, P. 2002. *Managing construction supply chains: the common sense approach. Engineering Construction and Architectural Management*, 9(5-6), 409-418.

Crosby, P. B. 1979. *Quality is free: The art of making quality certain.* New York: New American Library.

DDC. 2012. *BIM Guidelines – New York City Department of Design+Construction (DDC) (2012).* Retrieved from http://www.nyc.gov/html/ddc/downloads/pdf/DDC_BIM_Guidelines.pdf on April 21, 2015

East, B. 2014. *Construction-Operations Building Information Exchange (COBie).* Retrieved from http://www.wbdg.org/resources/cobie.php on June 11, 2015

Eastman, C. M., Teicholz, P., Sacks, R. & Liston, K. 2011. *BIM handbook : a guide to building information modeling for owners, managers, designers, engineers and contractors*. Hoboken, NJ, Wiley.

Forrester, E., B. Buteau, and S. Shrum. 2011. *CMMI® for Services: Guidelines for Superior Service.* Addison-Wesley Professional.

Government Construction Strategy: One Year On and Action Plan Update. 2012. UK, Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/61151/GCS-One-Year-On-Report-and-Action-Plan-Update-FINAL_0.pdf on June 5, 2015.

Indiana University. 2012. *BIM Guidelines and Standards for Architects, Engineers, and Contractors, Indiana University, 2012.* Retrieved from http://www.indiana.edu/~uao/iubim.html on May 14, 2015.

International Organization for Standardization. 1995. *Standard for information technology: software lifecycle processes. ISO/IEC Standard 12207.* International Organization for Standardization/International Electrotechnical Commission: Geneva, Switzerland, 87 pp.

International Organization for Standardization. 1998. *Software Engineering-Software Maintenance, ISO/IEC Standard 14764.* International Organization for Standardization: Geneva, Switzerland, 38 p.

International Organization for Standardization. 2011. *Information Technology: Process Assessment-ISO/IEC 15504.*

Joseph, J. 2011. *BIM Titles and Job Descriptions: How Do They Fit in Your Organizational Structure?*, Autodesk University 2011. Retrieved from http://aucache.autodesk.com/au2011/sessions/4436/class_handouts/v1_DL4436_Joseph_BIM_Titles_Job_Descriptions_JJ.pdf on June 11, 2015.

Jupp, J. R., & Singh, V. 2014. *Similar Concepts, Distinct Solutions, Common Problems: Learning from PLM and BIM Deployment*. In Product Lifecycle Management for a Global Market (pp. 31-40). Springer Berlin Heidelberg.

Kärkkäinen, H., Pels, H. J., & Silventoinen, A. 2012. *Defining the customer dimension of PLM maturity*. In Product lifecycle management. Towards knowledge-rich enterprises (pp. 623-634). Springer Berlin Heidelberg.

Kreider, R., Messner, J., and Dubler, C. 2010. *Determining the Frequency and Impact of Applying BIM for Different Purposes on Building Projects.* in Proceedings of the 6th International Conference on Innovation in Architecture, Engineering and Construction (AEC) (Penn State University, University Park, PA, USA, 2010). Retrieved from http://www.engr.psu.edu/ae/AEC2010 on March 25, 2015.

Krueger, R. A. .2009. *Focus groups: A practical guide for applied research.* Sage.

Kymmell, W. 2008. *Building Information Modeling, Planning and Managing Construction Projects with 4D CAD and Simulations.* McGraw-Hill Companies, Inc, US.

Liberda, M., Ruwanpura, J., and Jergeas, G. 2003. *Construction Productivity Improvement: A Study of Human, Management and External Issues.* Construction Research Congress: pp. 1-8.

Liston, K. M. K. 2009. *A mediated interaction approach to study the role of media use in team interaction*, PhD dissertation, Stanford University.

McGraw-Hill Construction. 2009. *McGraw-Hill Construction SmartMarket report, The Business Value of BIM: Getting Building Information Modeling to the Bottom Line.* Retrieved from http://www.bim.construction.com/research on May 2, 2015.

McGraw-Hill Construction. 2012. *McGraw-Hill Construction SmartMarket report, The Business Value of BIM in North America: Multi-year trend analysis and user rankings (2007-2012).* Retrieved from http://www.bim.construction.com/research on May 2, 2015.

Mell, P., and Grance, T. 2011. *"The NIST definition of cloud computing."* National Institute of Standards and Technology (NIST) special publication 800-145, Gaithersburg, MD, 7 pages.

Mihindu, S. and Arayaci, Y. 2008. *Digital Construction through BIM Systems will Drive the Re- engineering of Construction Business Practices.* Visualisation, 2008 International Conference, 9-11 July 2008, 29-34.

Musonda, H. and Muya, M. 2011. *"Construction Dispute Management and Resolution in Zambia."* J. Leg. Aff. Dispute Resolut. Eng. Constr., 3(4), 160–169.

NIBS. 2007. *National building information modeling standard- version 1.0 – part 1: Overview, principles and methodologies*, National Institute of Building Sciences, US.

NIBS, 2012. *National building information modeling standard- version 2,* National Institute of Building Sciences, US.

NIBS. *COBie Construction Templates*. Retrieved from http://www.nibs.org/?page=bsa_cobietemplate on July 5, 2015.

OPM3. 2003. *Organizational project management maturity model*. Project Management Institute, USA.

Paulk, M. C., Curtis, B., Chrissis, M. B., & Weber, C. V. 1993. *Capability maturity model, version 1.1.* Software, IEEE, 10(4), 18-27.

Pettee, S. R., *"Constructability Reviews — An Introduction",* Construction Management Association of America. Retrieved from https://cmaanet.org/files/Constructiblity%20Reviews%20-%20a%20primer%206-6-12%20versionFINAL.pdf on January 12, 2015.

Sebastian, R. & Van Berlo, L., 2010. *Tool for Benchmarking BIM Performance of Design, Engineering and Construction Firms in The Netherlands.* Architectural Engineering and Design Management, 6:4, 254-263.

SEI. 2010a. *CMMI for Development, Version 1.3, Improving processes for developing better products and services.* Software Engineering Institute, Carnegie Mellon University, US.

SEI. 2010b. *CMMI for Services, Version 1.3.* Improving processes for better products: Software Engineering Institute / Carnegie Mellon.

Smith, D. K., & Tardif, M. 2009. *Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers.* John Wiley & Sons.

Solibri. *Solibri Model Checker*. Retrieved from http://www.solibri.com/products/solibri-model-checker/ on September 2015.

Stark, J. 2011. *Product lifecycle management: 21st century paradigm for product realization*. Springer.

Staub-French, S., Forgues, D. & Iordanova, I. 2011. *Building Information Modeling (BIM) 'Best Practices' Project Report.* University of British Colombia, École de Technologie Supérieure.

Succar, B. 2010a. *Building information modelling maturity matrix. Handbook of research on building information modelling and construction informatics: Concepts and technologies.* J. Underwood and U. Isikdag, eds., IGI Publishing, 65-103.

Succar, B. 2010b. *The Five Components of BIM Performance Measurement*, 2010 CIB World Congress. Salford, United Kingdom.

Succar, B., Sher, W., & Williams, A. 2012. *Measuring BIM performance: Five metrics.* Architectural Engineering and Design Management, 8(2), 120-142.

Teicholz, P. 2004. *Labor Productivity Declines in the Construction Industry: Causes and Remedies.* AECbytes Viewpoint, 4.

Wegelius-Lehtonen, T. 2001. *Performance measurement in construction logistics.* International journal of production economics, 69(1), 107-116.